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The vagaries of the sea: evidence on the real effects of money from maritime disasters in the Spanish Empire *

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Abstract

Maritime disasters in the Spanish Empire (1531-1810) resulted in the loss of substantial amounts of silver money. We exploit this recurring natural experiment to estimate the effect that an exogenous change in the money supply has on the real economy. We find that negative money supply shocks caused Spanish real output to decline. A transmission channel analysis highlights slow price adjustments and credit frictions as channels through which money supply changes affected the real economy. Especially large output declines occurred in textile manufacturing against the backdrop of a credit crunch that impaired merchants' ability to supply their manufacturers with inputs.

Keywords: monetary shocks, credit channel, price rigidity, wage rigidity, local projection

JEL Codes: E43, E44, E52, N10, N13

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1. Introduction

The Columbian voyage of 1492 marked the beginning of three centuries in which vast amounts of monetary silver were shipped from America to Spain. During that time, Spain's money supply was subjected to the vagaries of the sea: maritime disasters that resulted in the loss of silver-laden ships gave rise to random contractions in the amount of money that arrived in Spain. We exploit this repeated natural experiment to obtain well-identified estimates of the causal effects of an exogenous money supply change.

To conduct the empirical analysis, we compile a novel dataset of maritime disasters in the Spanish Empire. For each maritime disaster we collect data on the quantity of silver lost, the cause of the disaster, and the quantity of silver that was salvaged in the aftermath of the event. When brought to bear on production indicators for early modern Spain, this data reveals that a negative shock to silver inflows amounting to 1% of the Spanish money supply led to a 1% drop in real output that persisted for several years. Disaggregated data suggests that the downturn was especially pronounced in textile manufacturing.

Through which channels did money affect economic activity? Our analysis highlights nominal rigidities and credit market frictions as important transmission channels. In response to the negative money shock, lending rates increased by 1 to 2 percentage points. In addition, contemporary merchant letters indicate that the monetary contraction caused a credit crunch during which credit became severely rationed. This impaired merchants' ability to provide their manufacturing networks with input goods. As a consequence, manufacturing input prices plunged for several years. By contrast, the prices for many output goods fell only gradually. Absent an instantaneous adjustment of prices, the scarcity of money weighed on the transaction volume of goods.

We assess the effect of money supply changes on the real economy by estimating impulse response functions (IRFs) based on our money shock measure. We do so using local projections and autoregressive models. The resulting IRFs compare the trajectories of macroeconomic variables across years that are exposed to exogenous variation in the money supply. Clean identification requires that our IRF estimates are not contaminated by the influence of correlated shocks. We present evidence in support of this assumption using several robustness checks and diagnostic statistics, including pre-event analyses and placebo tests. Importantly, we show that maritime disasters on outbound voyages, in which no monetary metals were lost, had no effect on Spanish economic outcomes. This finding moderates concerns that maritime disasters exerted their effect in non-monetary ways, such as through the loss of ships, cargo, and lives. We also show that our IRF estimates are not driven by the loss of Crown revenues, which typically amounted to significantly less than one fifth of money arrivals. While maritime disasters could trigger sovereign debt crises, Spain's early modern public sector was too small for this to generate noticeable spillover effects into private sector lending rates or aggregate economic outcomes.

The first contribution of this paper is to provide well-identified, reduced-form estimates of the causal effects of money supply shocks. In doing so, we add to the body of evidence that sheds light on the interaction between money and the real economy based on historical monetary experiments (Velde, 2009; Palma, 2021). In contrast to Palma (2021), who highlights the influence of American silver production on Western European economies, we focus on the influence of disaster-related monetary losses on the Spanish economy. Beyond documenting a causal effect, our analysis draws on an extensive body of disaggregated data to indicate the transmission channels through which money affected the real economy. Our identification strategy is inspired by Koudijs (2015, 2016), who exploits weather-induced interruptions to shipping traffic across the English Channel in the early modern period to analyze how information flows affect stock market valuations. The strength of the experimental approach is that it requires few assumptions to identify causal effects. This luxury is seldom provided to studies of monetary policy, which usually are more demanding in this respect. Methodological examples include structural VARs (Christiano, Eichenbaum, and Evans, 1999; Uhlig, 2005; Bernanke, Boivin, and Eliasz, 2005; Coibion, 2012), estimated DSGE models (Ireland, 1997, 2003; Smets and Wouters, 2007), instrumental variable strategies (Jordà, Schularick, and Taylor, 2020) often applied in combination with high frequency data (Gertler and Karadi, 2015; Miranda-Agrippino and Ricco, 2018; Nakamura and Steinsson, 2018a), and narrative approaches to identifying monetary shocks (Friedman and Schwartz, 1963; Romer and Romer, 1989, 2004; Cloyne and Hürtgen, 2016). Comprehensive overviews of common identification methods in macroeconomics are provided by Ramey (2016) and Nakamura and Steinsson (2018b).

The second contribution of this paper is to trace the real effects of money through its various transmission channels (e.g. Mishkin, 1995; Kuttner and Mosser, 2002; Auclert, 2019). In this regard, our findings underscore the relevance of nominal rigidities (Calvo, 1983; Christiano, Eichenbaum, and Evans, 2005; Nakamura and Steinsson, 2013; Gorodnichenko, Sheremirov, and Talavera, 2018), and credit frictions (Kiyotaki and Moore, 1997; Carlstrom and Fuerst, 1997; Bernanke, Gertler, and Gilchrist, 1999). That these two channels – so familiar to economists today – were already relevant in the early modern period points to their deep-rooted influence on macroeconomic fluctuations.

The remainder of the paper is structured as follows. Section 2 introduces the data and describes our empirical strategy. Our estimates of the real output effects of money supply changes are reported at the beginning of section 3. The section continues with the transmission channel analysis (3.2) and a discussion of correlated shocks (3.3). Section 4 concludes.

2. Money supply shocks and econometric method

This section works toward obtaining reduced-form estimates of the causal effects of money on the economy. It begins with a description of the Spanish monetary system in the early modern period and then presents our shock measure, data, and econometric strategy.

2.1. Money and precious metal inflows in early modern Spain

Money in early modern Spain consisted mainly of coins made of precious metals – above all silver (Palma, 2021).[1] In terms of functionality, early modern precious metal money is comparable to narrow money aggregates today. Other varieties of money existed, but precious metal coins were more widely accepted than their surrogates, such as banknotes (Nightingale, 1990). As late as 1875, gold and silver made up 85% of the Spanish money supply (Tortella et al., 2013, p.78). Our analysis therefore focuses on gold and silver coins, which we interchangeably name "money" in the following.

Spain's money supply was heavily influenced by the inflow of precious metals from America (Desaulty et al., 2011). Annual arrivals were large, ranging from 1% to 15% of the Spanish money stock (Chen et al., 2021). Precious metal inflows primarily constituted remittances and transfers of income from abroad.[2] Regulation required all arriving precious metals to be minted (Hamilton, 1934, pp.25,20). Over time, more and more of America's precious metal output was already minted in American mints (Céspedes del Castillo, 1996; Irigoin, 2020). Thus, by the 18th century, the vast majority of precious metals that arrived in Spain did so in coined form (Costa et al., 2013; de Paula Perez Sindreau, 2016, p.63).[3]

[1] Copper coins also played a role, but they were only practicable for small transactions (Sargent and Velde, 2002), and their prominence fluctuated over time (Motomura, 1994). Only for a few decades after 1617 did copper coins make up a significant share of Spain's overall money supply (Velde and Weber, 2000).

[2] Only between one tenth and one third of precious metal inflows from America constituted payment for Spanish exports (based on export values from Phillips, 1990, p.82). The annual data on Spanish exports to America that becomes available from the late 18th century onward (Esteban, 1981) exhibits no correlation with Spain's precious metal inflows (Table B.1 in the Appendix). Also note that, because a typical round trip from Spain to the colonies took somewhat more than a year (Chaunu and Chaunu, 1977, pp. 229ff.), it is possible to account for any export correspondent of money inflows by controlling for lagged indicators of Spanish economic activity.

[3] Some silver shipments were insured (Baskes, 2013). To the extent that silver shipments were insured within the Spanish merchant community maritime disaster losses still constituted an aggregate shock to the Spanish money supply. Foreign insurers also existed, but no quantitative information exists about

Public authorities at Imperial mints guaranteed the silver content of the coinage, but precious metal mines were owned and run by private entrepreneurs (Elliott, 2006, p.93). For much of the early modern period 85% to 95% of precious metal remittances from America were privately owned (García-Baquero González, 2003; Costa et al., 2013). Only in the late 18th century did the Crown's share begin to exceed 20%. The annual arrival of treasure ships was scheduled in advance (Chaunu et al., 1955), and publicly available prognoses of how much precious metals would arrive were on average correct (Palma, 2021).[4] Thus, maritime disasters led to the loss of money that Spain's private sector thought it possessed.[5]

2.2. Maritime disasters

We collect data on maritime disasters from the historical literature on Spanish precious metal shipments (Chaunu and Chaunu, 1977; Morineau, 1985; Mangas, 1989; Walton, 1994; Bonifacio, 2010), catalogs of sunken treasure ships (Potter, 1972; Marx, 1987), and `todoavante.es` which provides a description of treasure fleet voyages based on primary archival sources. The main variables we collect are the date of a disaster, its location, its cause, the amount of precious metals lost, as well as the amount of precious metals that was salvaged. We restrict our data collection to maritime disasters that resulted in the loss of monetary gold and silver destined for Spain. The resulting list of events is described in Table 1. A detailed listing of the sources for each individual disaster event is provided in Table A.1 in the Appendix.

In total we observe maritime disasters that produced money shocks to the Spanish economy in 33 out of 280 years.[6] The most frequent cause of maritime disasters was bad weather, such as hurricanes. Navigational errors rank second. A third reason for the loss of silver was capture by privateers. The most notable such event occurred in 1628, when the Spanish fleet, carrying 80 tonnes of silver, was captured by Dutch privateer Piet Heyn. Finally, in three instances silver-laden ships were destroyed in naval combat. In 1804, for example, the Spanish treasure ship *Nuestra Señora de las Mercedes* was engaged by British naval forces off the coast of Portugal. In the ensuing Battle of Cape Saint Mary

the extent to which they were involved in insuring Spanish silver shipments. Our finding that European lending rates beyond Spain's borders did not systematically increase in the aftermath of maritime disaster losses indicates that money losses were predominantly born by Spanish entities (see Figure B.13 in the Appendix).

[4] *Avisos* – small and fast dispatch boats – brought news about the amount of treasure a fleet carried (Martín, 1965, p.lxxxvii).

[5] By regulation, transatlantic business with Spanish colonies was restricted to Spanish merchants (Nogues-Marco, 2011, p.6). As a consequence, a Spanish entity initially owned the arriving precious metals, even if most of it eventually diffused across Europe.

[6] The accident rate in terms of ship numbers and ship tonnage was below 5% (Chaunu et al., 1955, Tome VI-1, pp. 869-871) – considerably lower than the fraction of disaster years.

the treasure ship exploded, resulting in the loss of more than 35 tonnes of silver.

We argue that these events constitute useful natural experiments. Bad weather as well as navigational errors were unrelated to economic conditions in Spain. Capture and combat admittedly were rooted in interstate conflicts that affected the Spanish economy in more ways than just through the influx of silver. Conditional on that, however, the capture and destruction of silver ships was driven by the random emergence of tactical opportunities, not the evolution of economic variables in Spain. Moreover, our results are robust to excluding conflict-based events. To test whether maritime disasters were in any way related to economic conditions in Spain we also look at the pre-disaster behavior of economic variables. The pre-event analysis confirms that maritime disasters were not preceded by systematic fluctuations in the Spanish economy (Figure B.12 in the Appendix).

To arrive at our money supply shock measure, we divide the absolute silver losses from Table 1 by the money stock level provided in Chen et al. (2021). More concretely, we express each silver loss as a fraction of the preceding year's money stock.[7] The timing of the shock to the Spanish economy furthermore depends on the location where the maritime disaster took place. For example, it took about 3 months for precious metals loaded in Portobelo (Panama) and Cartagena (Colombia) to arrive in Spain. Fourth quarter maritime disasters in this area thus constituted shocks to Spain's money supply one year ahead. We use the detailed information on return shipping times from Chaunu and Chaunu (1977, pp. 229ff.) to determine the timing of the shocks.[8] The resulting shock measure is depicted in Figure 1. Grey markers indicate the money loss excluding salvaged amounts. On average, maritime disasters shocks resulted in a loss of money that amounted to 4.1% of the Spanish money stock. The shock's size ranged from 0.02% to

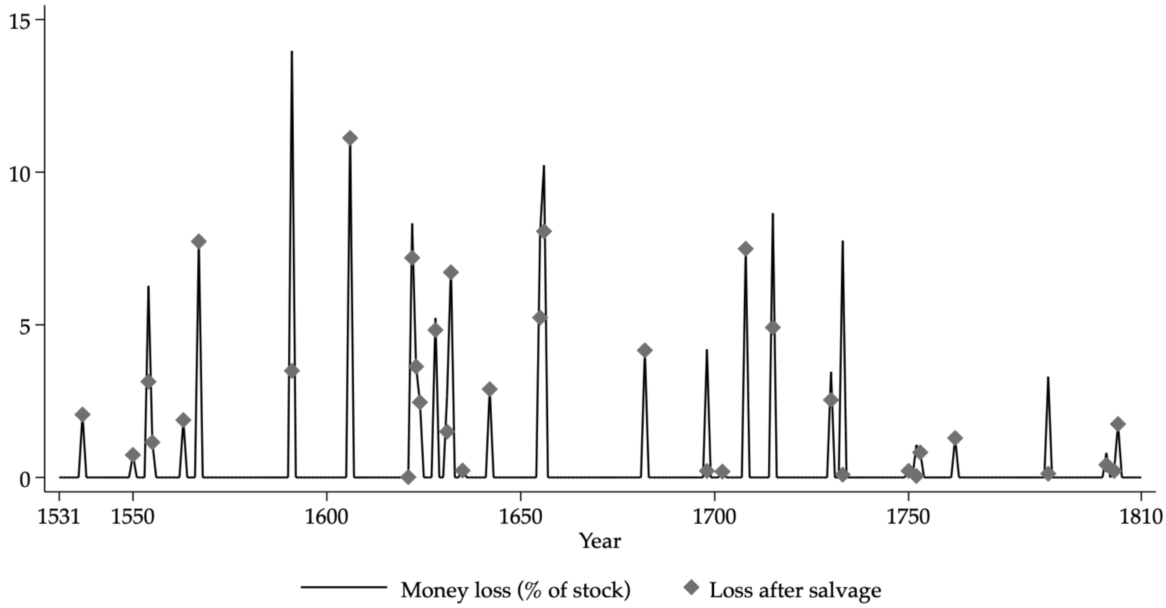
[7]Absent annual data on Spanish money in- and outflows vis-à-vis other countries it is impossible to determine how shocks to Atlantic money inflows affected Spain's overall money growth rate. International monetary models, such as Hume's price-specie flow model (Hume, 1752), or the monetary approach to the balance of payments (Flynn, 1978; Frenkel and Johnson, 2013) predict that Spanish money losses eventually diffused across Spain's borders. Fragmentary trade data indicates that Spain indeed imported less from abroad in the aftermath of a contractionary money shock, but it did not succeed in increasing its exports (see section B.1 in the Appendix). The prolonged response of Spanish prices suggests that loss diffusion did not occur quickly (see section 3.2.2). In fact, for the majority of prices a sustained recovery only set in five years after the shock, indicating that Spain's money stock acted as a buffer between precious metal inflows from America and other European countries' money stocks. This notion is further supported by the lack of a systematic lending rate response beyond Spain's borders (see Figure B.13 in the Appendix).

[8]We apply the following travel times to Spain: European coasts: 0 months, Azores: 0.5 months, Bermudas: 1.5 months, Havana: 2 months, Cartagena: 2.75 months, Portobelo: 3 months, Veracruz: 4 months, Lima: 4 months, Rio de plata: 4 months. We attribute each maritime disaster to its most recent place of departure. E.g. to a maritime disaster occurring on the Veracruz-Havana leg of the New Spain fleet we attribute a 4 month travel time. A robustness check in which we assume that travel times lasted one month longer produces very similar results (Figure B.9 in the Appendix).

Table 1: Maritime disaster events

Year	Silver loss	Cause of maritime disaster	Salvaged silver	Location	Month
1537	18,258 kg	capture	NA	Azores	Sep
1550	2,693 kg	navigational error	0 kg	Azores	Jun
	5,386 kg	weather	0 kg	Havana	Jun
1554	73,031 kg	weather	36,516 kg	Veracruz	Apr
1555	12,781 kg	weather	0 kg	Veracruz	Jan
1563	24,430 kg	weather	0 kg	Bermudas	Sep
1567	109,547 kg	weather	0 kg	Havana	Apr
1591	255,610 kg	weather	191,708 kg	Azores	Sep
1605	204,488 kg	weather	0 kg	Havana	Nov
1621	382 kg	weather	128 kg	Bermudas	Sep
1622	188,951 kg	weather	25,561 kg	Havana	Sep
1623	76,345 kg	weather	0 kg	Havana	Sep
1624	51,122 kg	weather	0 kg	Havana	Apr
1628	30,538 kg	navigational error	8,339 kg	Veracruz	Jul
	80,660 kg	capture	NA	Havana	Sep
1631	150,241 kg	weather	4,427 kg	Veracruz	Oct
	58,169 kg	navigational error	25,561 kg	Portobelo	Jun
1634	7,635 kg	navigational error	2,556 kg	Havana	Nov
1641	76,683 kg	weather	0 kg	Havana	Oct
1654	255,610 kg	navigational error	89,464 kg	Lima	Oct
1656	127,805 kg	navigational error	63,903 kg	Havana	Jan
	122,693 kg	combat	0 kg	Europe	Sep
	51,122 kg	capture	NA	Europe	Sep
1682	153,366 kg	weather	0 kg	Cartagena	May
1698	161,540 kg	navigational error	153,366 kg	Havana	Mar
1702	5,308 kg	combat	0 kg	Europe	Oct
	2,042 kg	capture	NA	Europe	Oct
1708	281,171 kg	combat	0 kg	Cartagena	Jun
	5,112 kg	capture	NA	Cartagena	Jun
1715	309,972 kg	weather	133,969 kg	Havana	Jul
1730	139,556 kg	weather	37,215 kg	Havana	Sep
1733	311,908 kg	weather	308,246 kg	Havana	Jul
1750	6,748 kg	weather	359 kg	Havana	Aug
	3,573 kg	capture	NA	Havana	Aug
1752	49,620 kg	weather	47,345 kg	Rio de plata	Jul
1753	38,134 kg	weather	0 kg	Lima	Jan
1762	62,895 kg	capture	NA	Europe	May
1786	185,716 kg	navigational error	178,847 kg	Europe	Feb
1800	51,264 kg	navigational error	24,641 kg	Lima	Nov
1802	13,742 kg	weather	0 kg	Havana	Oct
1804	36,645 kg	combat	0 kg	Europe	Oct
	76,439 kg	capture	NA	Europe	Oct

Figure 1: Monetary shock measure



14%, with a median value of 3.1%.[9]

2.3. Outcome variables

We analyze two types of outcome variables: First, variables that describe real economic output. Second, variables that describe channels through which money shocks might have affected real economic output in the early modern Spanish economy.

Real economic output. Economic historians have recently rebuilt early modern national accounts for many countries using large amounts of data from sources such as probate inventories and the account books of monasteries, universities, and hospitals. In this vein, Álvarez-Nogal and Prados de la Escosura (2013) have compiled an annual time series on Spanish real output that covers our sample period.[10] This series is based on a demand function approach that combines data on incomes (wage rates and land rents) and goods prices (agricultural and manufacturing output prices) into an estimate of real GDP.[11] We use this series to obtain an impression of how Spain's aggregate economic

[9]Our money shock measure resembles a (negative) helicopter drop in that it directly altered the level of monetary assets held by the private sector.

[10]While the original publication presents 11-year moving averages the authors have kindly shared the underlying annual data with us.

[11]The baseline GDP estimate by Álvarez-Nogal and Prados de la Escosura (2013) also incorporates urbanization rate data that is interpolated over several decades. As this interpolated data is uninformative with respect to our analysis of short-run monetary effects we remove it from their GDP estimate. This leaves the shape and statistical significance of the real output response unaffected, but increases its

activity responded to money supply shocks.

While recent efforts by economic historians have produced much improved macro aggregates for the early modern period, their construction is based on stronger assumptions than that of their modern equivalents.[12] To address this concern our analysis includes a wide range of disaggregated data which originates from the account books of companies, notarial deeds, and the tax records of cities and guilds. This data is region-, sector-, and period-specific (e.g. 16th century Segovian textile production). We use these fragments to broaden the evidence base and throw additional light on the sectoral response of the Spanish economy.

First, Phillips and Phillips (1997, Appendix I) provide annual data on wool production approximated by the size of the flock of sheep. From the beginning of our sample up to 1563 the number of sheep under the jurisdiction of the *Mesta* – a Castilian livestock owners' association – was counted annually to assess membership fees.[13] After that, the annual count was replaced by a rough estimate, until in the early 1600s annual counts resumed for two decades (Klein, 1920, p.27).[14] Throughout, the *Mesta* accounted for a significant fraction of total Spanish wool production (20-50% according to Phillips and Phillips, 1997, p.291, Figure A1.1).

Second, García Sanz (1977) has compiled an annual time series on the production of fine cloths in Segovia. Segovia was Spain's most important textile manufacturing center (Massana, 1999, p.36). At times, close to 50% of its population worked in textile manufacturing (Le Flem, 1976, p.531). García Sanz' series spans almost a century, from 1699 to 1790, providing us with extensive insight into how one of early modern Spain's most prominent manufacturing industries responded to money supply shocks.

Third, the tax records of the city of Toledo provide another data source that is informative with respect to economic activity in Spain's textile manufacturing sector. Toledo was a key transit hub for the distribution of textiles (Montemayor, 1996, p.239), and each year it auctioned off the right to collect taxes on cloths entering the city. Most textiles came to Toledo for final finishing and subsequent re-export: Segovian textiles, for example, passed through Toledo before reaching their Southern customers. Similarly, many Valencian textiles first arrived in Toledo before continuing to their Northern customers. The Toledean tax data is therefore informative with respect to activity in Spain's tex-

absolute size by around one third.

[12]For details about the reconstruction procedures see de Jong and Palma (2018). For details about the typical data sources used see Palma (2020).

[13]While the Mesta flock size data is dominated by sheep, it also includes cows, horses, goats, and swines. The time series by Phillips and Phillips (1997) adds the latter animals to the overall Mesta flock size number according to the following key: 1 cow = 1 horse = 6 sheep; 1 goat = 1 swine = 1 sheep.

[14]The flock size was usually counted during hibernation in Extremadura. The annual flock size given by the sources thus represents beginning-of-year values. We shift this series one year forward to facilitate the interpretation of our impulse response function results.

tile manufacturing sector more generally. Montemayor (1981) has compiled the existing annual data on Toledean tax auction revenues for coarse and fine cloths (1540–1660).[15] The resulting series complement the textile output series by García Sanz, and enable us to evaluate the reaction of Spanish textile manufacturing for an earlier time period and a wider production region. Montemayor (1981) furthermore provides an annual tax revenue series that covers foodstuffs sold in the Toledean market.[16] We use this series to throw additional light on the behavior of primary goods consumption in the aftermath of money shocks.[17]

Finally, Odriozola Oyarbide (2002) has compiled an annual time series on Basque ship building that covers our entire sample period. This time series summarizes information from the purchase contracts and notarial deeds that have survived in Basque archives. It misses smaller ships that have been commissioned on a handshake basis without notarial help. The Basque region was an important shipbuilding hub in early modern Spain. The time series by Odriozola Oyarbide is therefore indicative of overall Spanish ship production. A caveat pertains to the analysis of this series given the nature of the money shock we analyze: to the extent that ship owners wanted to replace the ships they had lost in maritime disasters, the shipbuilding response mixes monetary effects with an increase in replacement demand.

Transmission channels. A multitude of price and wage series exist for early modern Spain. They allow us to trace the nominal adjustment of Spain's economy to money shocks in considerable detail. On the aggregate level, Álvarez-Nogal and Prados de la Escosura (2013) provide consumer price and wage series that cover our entire sample period. These series form the data basis for our headline price and wage IRFs. We further unpack Spain's nominal adjustment by drawing on disaggregated price and wage series.

There exist a large number of goods-level price series for early modern Spain – more than is practical to analyze individually (e.g. Hamilton, 1934, 1947; Losa and Zarauz, 2021). We therefore aggregate the available price series into equi-weighted price indices

[15] We deflate the two nominal auction revenue series with a Spanish cloth price index. We calculate this cloth price index as an equi-weighted average of the cotton, hemp, twine, and linen cloth price series provided by Losa and Zarauz (2021) and Allen (2001). The nominal tax receipt series produce almost identical IRF estimates, as the response of cloth prices to money supply shocks was moderate.

[16] We deflate the foodstuffs tax revenue series with a food-heavy consumer price index for New Castile from Reher and Ballesteros (1993). We obtain very similar IRF results when deflating the foodstuffs tax series with an equi-weighted index of all the Madrilenian food price series provided by Losa and Zarauz (2021).

[17] To the extent that tax farmers were risk averse and money shocks increased uncertainty about tax revenues, tax farmers' bids may incorporate an additional risk premium in the aftermath of maritime disasters. Part of any initial tax auction return decline may thus reflect a higher risk premium rather than lower expected tax revenues. Such a risk premium is likely to diffuse once the dust has settled one to two years after the shock, leaving the validity of the IRF estimate for all subsequent horizons unaffected.

that cover various product categories of interest (e.g. animal products, threads, coarse and fine cloths). Table A.2 in the Appendix describes the sources, the series, and how we combine them into product-category price indices.

Disaggregated wage series are somewhat less plentiful than disaggregated price series (e.g. Hamilton, 1934; Feliu, 1991; Losa and Zarauz, 2021). However, enough data exists to distinguish between important occupational categories (e.g. skilled versus unskilled labor, primary sector versus secondary sector). Table A.3 in the Appendix describes sources, series, and their aggregation into wage indices for different occupational groups. Besides throwing additional light on how money shocks worked their way through Spain's economy, the disaggregated price and wage series also allow us to draw some conclusions about the types of nominal frictions that were present.

Time series that convey information about credit market conditions are more difficult to obtain. Usury laws led to the hiding of interest payments. Additionally, many original sources were lost and no longer exist (Homer and Sylla, 1991; Pike, 1966, p. vi). Fortunately, lending rates left their mark in exchange rates – more particularly in the prices of bills of exchange that were systematically quoted in financial markets throughout Europe.

The exchange rate embodied in a bill of exchange differs from the spot exchange rate in that it describes the amount of currency to be delivered at one place today in exchange for another currency at another place at a later date. This time delay means that bills of exchange combined a spot exchange transaction with a lending transaction. In fact, against the background of the prohibition of many types of lending through usury laws, bills of exchange became Europe's dominant lending instrument. They allowed lending rates to be hidden within what on the surface was a foreign exchange contract (Bell et al., 2017; Flandreau et al., 2009; de Roover, 1967; de Malynes, 1601).

Extensive datasets of early modern bill of exchange quotations have been compiled (Da Silva, 1969; Schneider et al., 1992, 1994; Denzel, 2010), enabling us to throw light on the fluctuations in lending rates that Spanish merchants faced. Appendix A.3 provides a detailed description of how we use bill of exchange prices to infer the behavior of lending rates in Spain.[18] We complement the lending rate data with information contained in merchant letters that have been compiled by economic historians (da Silva, 1959a; Martín, 1965; Lockhart et al., 1976). In some of these letters, contemporary merchants describe the credit market conditions they faced in the aftermath of maritime disaster events. Importantly, these letters describe episodes of credit rationing which the observable lending rate data does not reflect.

[18]The calculated interest rate fluctuations are best regarded as fluctuations in risky lending rates, rather than risk-free rates. Lenders were generally perceptive of the riskiness of borrowers' financial position, and high lending rates were charged to compensate for high default risk (Carrasco González, 1996, ch.2).

2.4. Econometric method

We use local projections (Jordà, 2005) to estimate impulse response functions (IRFs) over a five-year horizon, $h = 0, ..., 5$:

$$(Y_{t+h} - Y_{t-1})/Y_{t-1} = \alpha_h + \beta_h S_t + \gamma_h X_t + u_{t+h} \quad (1)$$

where Y_t is the outcome of interest (output, prices, wages, interest rates). u_{t+h} denotes the horizon-specific error term. S_t is the money supply shock. X_t comprises control variables, including the part of the initial money loss that is subsequently salvaged.[19] The estimated β_h coefficients describe the cumulative response of the outcome variable to a monetary shock: β_0 captures the cumulative response between period $t-1$ and t, β_1 captures the cumulative response between period $t-1$ and $t+1$, and so on.

The baseline specification includes up to two lags, five leads, and the contemporaneous values of the following exogenous control variables: the money supply shock S_t, the amount of money that was salvaged after a maritime disaster (% of stock), silver lost due to capture (% of stock), Spanish temperatures, and indicators of the number of military conflicts that Spain was involved in (based on the historical conflict catalogue by Brecke, 1999). Finally we also include two lags and, with the exception of the dependent variable, the contemporaneous values of the following endogenous controls: price level growth, wage growth, real GDP growth, and changes in the money inflow-to-stock ratio.[20] As is common in IRF analyses based on local projections, we saturate our baseline specification with a rich set of control variables (Stock and Watson, 2018; Jordà et al., 2020). A more parsimonious specification that besides the lagged dependent variable's growth rate contains only the silver shock regressors results in similar IRF estimates (Figure B.5 in the Appendix).[21] The shortness of some of the disaggregated time series requires us to thin

[19]Alternatively, it is possible to account for salvaging by directly subtracting salvaged amounts from the shock measure. Figure B.7 in the Appendix shows very similar results for this approach.

[20]The first half of the 17th century witnessed the spread of copper coins in the Spanish economy. For a period of several decades, copper coins made up a substantial fraction of the overall Spanish money supply. We therefore allow the effects of money shocks to differ for the period 1617 to 1664. The beginning of that period is marked by the public authorities' decision to allow the minting of copper coins. Copper minting became largely inconsequential after 1664 when a decision was made to halt minting. While copper money existed before and after this period, its role was much diminished. Only within the 1617 to 1664 time window did copper play an important role in the Spanish monetary system (Velde and Weber, 2000).

[21]The robustness of the results with respect to various other relevant alterations in specification and shock measure is documented in Appendix B. The results are robust to excluding money shocks that were rooted in international conflict (capture and combat events) from the analysis (Figure B.6). We obtain very similar results when we estimate IRFs through an autoregressive distributed lag (ARDL) model as in Romer and Romer (2004) and Cloyne and Hürtgen (2016) (Figure B.8). We also construct an alternative shock series under the assumption that the news about a disaster took one month longer than usual to arrive in Spain, which yields very similar results (Figure B.9). The calculation of placebo IRFs based on 500 random temporal reshufflings of the shock measure yield results centered around 0

out the set of control variables to prevent the number of coefficients from exceeding the number of observations. In these cases we fall back onto the parsimonious specification.[22] For each estimated IRF we report point-wise confidence bands, based on Newey-West standard errors with the lag order of autocorrelation equalling five (Newey and West, 1987).

3. The causal effects of money supply shocks

3.1. Output effects

What was the real effect of exogenous money supply changes on the Spanish economy? Figure 2 displays the shock and its impact on aggregate economic activity. The money shock IRF describes a one-off reduction in money inflows amounting to 1% of the money stock. The IRF's quick return to zero one year after the impulse shows that subsequent Atlantic inflows did not compensate for the initial maritime disaster loss. In response to the shock, Spanish real output begins to fall. Output troughs one year later at around 1% below its trend level. Output stays below trend for several years before fully recovering four years after the shock.

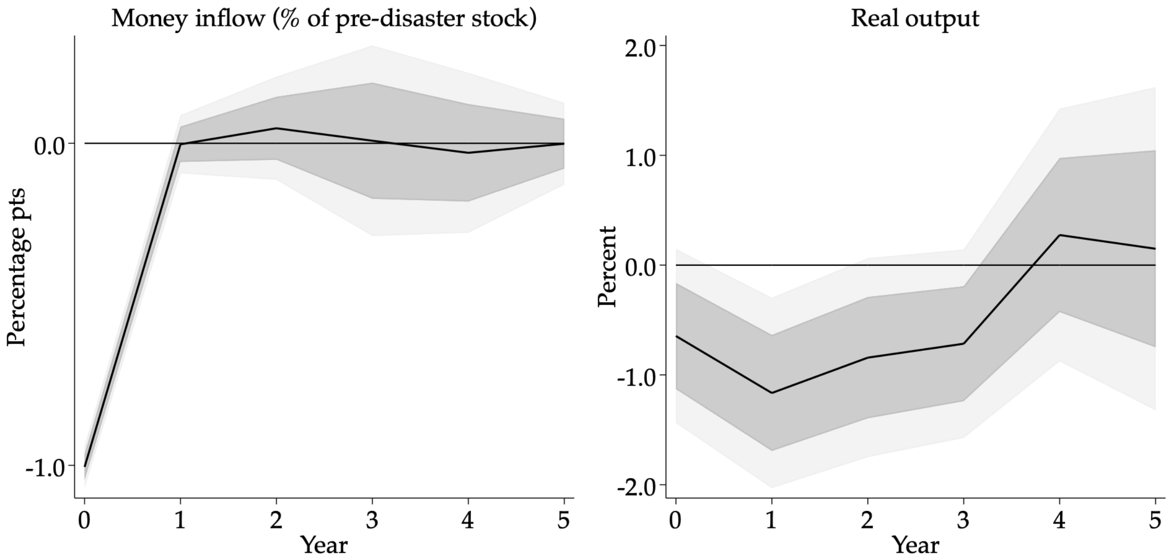
We now turn to the analysis of the disaggregated output data. The top left panel of Figure 3 shows primary sector responses. Foodstuffs consumption responded only modestly.[23] By contrast, wool production displays a striking response. Sheep flock sizes drop by 7% within one year. Various pieces of evidence suggest that herd owners liquidated their livestock in an attempt to raise money. First, high lending rates and merchant letters reflect a scramble for liquidity occurring in the aftermath of money losses (see section 3.2.1). Second, consistent with an increase in the supply of meats, the price for mutton and beef fell quickly (see section 3.2.2). Finally, selling commodities to overcome a liquidity shortage was common practice in early modern Spain. The historical literature documents accounts of wool merchants that lament having to sell part of their flock to raise money precisely when prices are lowest (Martín, 1974, p.278). Even those who did not own any commodities could participate in their sell-off (Pike, 1966, p.44): Contemporary theologian-economist de Mercado (1587, chapter XXII) describes a specific contract type – the *barata* – that allowed those in need of money to borrow commodities from wholesalers

(Figure B.10), confirming that our shock measure does not simply pick up a spurious relation between the variables.

[22]This applies to the following series: Mesta flock size, Segovian textile production, Toledean coarse and fine textiles.

[23]Separate Toledean tax revenue series for fish and cereals allow us to further distinguish between essential and luxury food items (Montemayor, 1981). Whereas the consumption of cereals responds similarly to all other foodstuffs, the consumption of fish – a luxury good – declines more markedly. This is indicative of belt-tightening behavior among households (Figure B.1 in the Appendix).

Figure 2: Real output response to a negative 1 percentage point money inflow shock



Notes: Gray areas – 1 standard deviation and 90% confidence bands.

and immediately sell them at a substantial discount to raise the much needed cash. A fire sale of livestock is thus a compelling explanation for the sharp drops in flock size that we observe in the aftermath of contractionary money supply shocks.[24]

Further down the production chain, textile production in Segovia falls by 2% on impact (see top left panel of Figure 3). Production then remains 2% below trend for another two years before showing any signs of recovery. The lower left panel of Figure 3 confirms the textile industry's contraction based on the Toledean tax data. Cloth entries into Toledo decrease between 2% and 4%. Compared to the Segovian production data, Toledean cloth entries exhibit a delayed response, and the IRF for fine cloth entries is estimated less precisely than that for coarse cloths.[25] Generally, however, the two Toledean tax series corroborate the evidence for a contractionary effect of money supply shocks on textile manufacturing.[26]

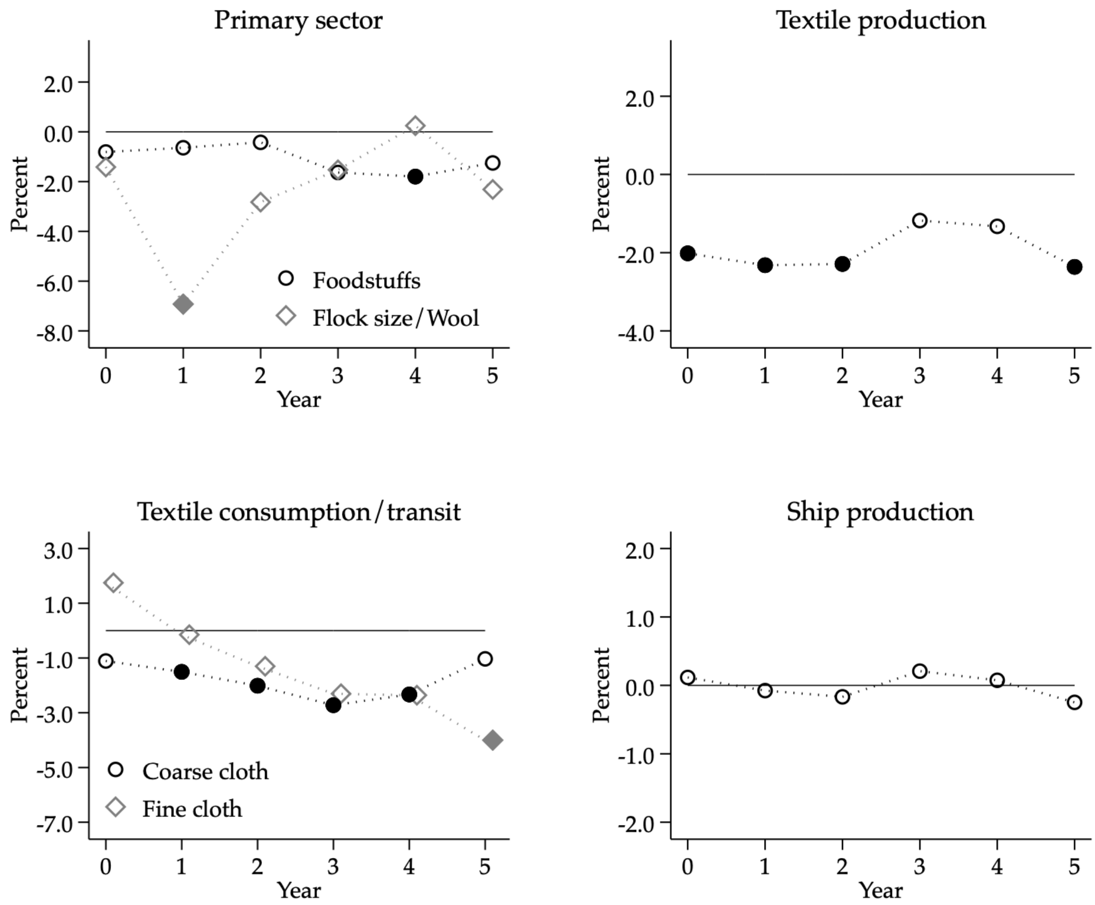
We conclude our analysis of output quantities with a look at ship production. The lower right panel of Figure 3 shows that Basque shipbuilding did not react to the monetary shock. In our setting, the shipbuilding response has added relevance, because ships were

[24] Another potential explanation springs from the fact that shepherds obtained credit and cash from local landlords to supply their herds, e.g. with salt (Carrère, 1974, p.208). A scarcity of money and credit may thus have forced a reduction in flock size as shepherds became unable to sustain their herds. However, the drop in flock size is exceedingly large and short-lived when compared to production declines in other industries that relied on credit to purchase intermediate inputs (e.g. textile manufacturing).

[25] One potential explanation for the delayed response is that tax auction revenues can reflect bidders' backward-looking expectations rather than the current volume of taxable goods.

[26] Montemayor (1981) provides additional tax auction returns for tax rights pertaining to Toledean theater and brothel revenues. The results for these series, appropriately deflated, are shown in Figure B.1 in the Appendix. Brothel visits decline gradually, whereas theater visits do not respond significantly.

Figure 3: Real output responses to a negative 1 percentage point money inflow shock



Notes: Solid markers – significance at the 10% level. Hollow markers – no significance at the 10% level.

lost in maritime disasters. While the value of ships lost was trivial compared to the value of money lost (see section 3.3.2), the replacement demand for new ships may nevertheless have contributed to stabilizing output in the shipbuilding industry. The lack of response of ship production indicates that if any such stabilization effect existed, it did not go beyond offsetting the negative effects springing from the maritime disaster shock.

In sum, the IRF estimates suggest that exogenous money supply changes have real effects. A 1% contractionary money shock is followed by a 1% decline in the aggregate output measure. Output declines are particularly large and persistent in textile manufacturing. The evidence presented in the subsequent sections highlights credit market frictions and slowly adjusting prices as important transmission channels through which money supply shocks exerted their influence.

3.2. Monetary transmission channels

This section analyzes the transmission channels through which money supply shocks affected the real economy. It does so by taking a closer look at the data for indications of whether certain transmission channels were active or not.

3.2.1 External financing and credit frictions

In an environment with credit frictions a contraction in money supply can increase default probability and the cost of external finance (Kiyotaki and Moore, 1997; Bernanke et al., 1999; Gertler and Karadi, 2011). In early modern Spain, money arrivals from America quickly found their way into the central nodes of the money market – financial exchanges and exchange fairs.[27] Here, merchants netted out their debts and settled any remaining net debt through the transfer of money (Vicens Vives, 1969, pp.374–375). Maritime disasters brought about a scarcity of liquidity and they lowered the net worth of those individuals who were the owners of the lost money.[28] Both raised doubts about final settlement at the exchange fairs. The heightened default risk increased the cost of external finance as lenders became more hesitant to extent credit and sellers became more reluctant to accept credit instruments for payment.

Despite the prohibition of many forms of interest rates, external financing played an important role in early modern Europe. Debt obligations commonly made up between half and two thirds of merchants' liabilities, implying asset-to-net-worth ratios in the 2 to 3 range (Costa, 1997; Gelderblom and Jonker, 2004; Oldland, 2010).[29] For Spain, an extensive study of 149 merchant housholds' post-mortem inventories from 17th century Toledo reveals an average asset-to-net-worth ratio of 2.2 (Pérez, 1992).[30] A snapshot of a

[27]This is reflected in a unique set of records from 1570 and 1571, which registered the outflow of American precious metals from their port of arrival together with their destination. These records reveal that the money's most important destination were Spanish regions that hosted important financial exchanges and exchange fairs (da Silva, 1965, p.67).

[28]A back-of-the-envelope calculation suggests that silver losses only amounted to a small fraction of the overall Spanish wealth level. The Spanish annual precious metal inflow-to-GDP ratio ranges from 0.4% to 6.8%, whereas the closest wealth-to-GDP ratios from Piketty (2014) are 7 for England in 1700, and 5 for Spain in 1901. Considering a wealth-to-GDP ratio in the 5 to 7 range, annual Spanish precious metal inflows only amounted to between 0.06% and 1.4% of the Spanish wealth level. Small wealth losses can nevertheless develop sizeable aggregate effects if they are amplified by a critical node in the economy, such as levered entrepreneurs or financial intermediaries whose decisions influence the economy's aggregate investment (Kiyotaki and Moore, 1997; Bernanke et al., 1999; Brunnermeier and Sannikov, 2014). Merchants that participated in the exchange fairs might have constituted such a critical node. Absent more detailed information on the exact incidence of the money loss, however, the liquidity and wealth effects entailed by the money shock cannot be easily disentangled.

[29]The most important suppliers of credit were wealthy merchants, merchant-bankers, ecclesiastical institutions, and nobles (Pike, 1965; Milhaud, 2015).

[30]In the calculation of this asset-to-net-worth ratio equity-like liabilities include ex ante capital and dowries brought into the merchant family through marriage.

merchant company's balance sheet from Cadiz in 1747 shows an asset-to-net-worth ratio of 2.8 (Bernal and Ruiz, 1992, pp.369-370).[31]

Spain's early modern manufacturing industry was characterized by the *putting-out system* in which producers received raw materials and intermediate inputs from merchants. Merchants, in turn, relied on smoothly functioning credit markets to finance their purchase of input goods (García Sanz, 1977; Montemayor, 1996, p.249). Thus, when the cost of external finance increased, the manufacturing industry's supply with input goods could dwindle. In this regard, it is difficult to overestimate the centrality of merchants in the early modern Spanish economy. Many weavers received threads, looms, and even lodging from their merchant (Vaquero, 2020; Carande Thobar, 1976, p.471). For 17th century Toledo, Pérez (1992, p.92) quantifies the linkage between merchants and producers based on post-mortem inventory data found in notarial deeds. He finds that it was common for one merchant to supply between 100 and 200 manufacturers, e.g. master weavers. Montemayor (1996, p.230) provides another example of 100 master silk weavers, who ensured subsistence for a total of 8000 people. The entire enterprise depended on only 10 to 12 large merchants for its supply of silk. Merchants' access to credit was thus crucial for the functioning of the wider economy.[32]

Figure 4 shows that a 1 percentage point reduction in money inflows led to a 1.5 percentage point increase in the lending rate. The lending rate remains elevated for several years after the shock.[33] However, the lending rate IRF does not exhibit an on impact response, despite the on-impact drop in textile production (see section 3.1) – a sector highly dependent on the input goods supplied by merchants. The conjunction of an immediate output contraction and a delayed lending rate increase can be indicative of an episode of credit rationing during which all but the most creditworthy borrowers lose access to credit (Stiglitz and Weiss, 1981). During such episodes observable lending rates fail to reflect the prohibitively high premiums faced by average borrowers. In contrast to the lending rates analysis, an analysis of merchant letters that were written in the aftermath of maritime disasters is indicative of credit rationing.

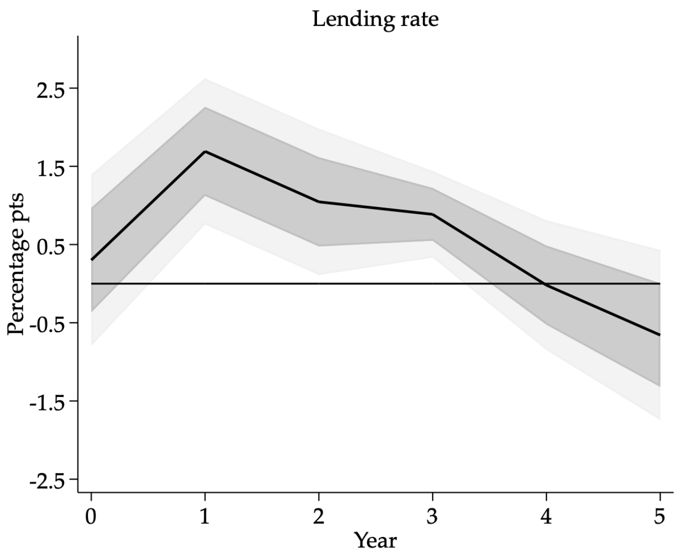
In a letter dated February 1568, ten months after the loss of monetary metals amounting to around 7% of Spain's money supply, a Spanish merchant complained about the lack

[31]This number results from treating credit-financed owner contributions as equity. Otherwise, the company was characterized by a higher asset-to-net-worth ratio.

[32]External financing also played a role in the Spanish colonial trade (Pike, 1962; Bernal and Ruiz, 1992; Carrasco González, 1996, p.160). That merchants and banks became busy "withdrawing and assigning", "charging and discharging" accounts as soon as a silver fleet had arrived demonstrates as much (de Mercado, 1587, p. 170). This activity was the complement to the loans that had been taken out by merchants to acquire merchandise, or by skippers to outfit their ships (Pike, 1966, p.75).

[33]As a placebo test we also estimated IRFs for the lending rates in several other Western European financial centers. The results show that lending rate increases are prevalent across Spanish cities whereas this is not the case for other European cities (Figure B.13 in Appendix B).

Figure 4: Lending rate response to negative 1 percentage point money inflow shock



Notes: Gray areas – 1 standard deviation and 90% confidence bands.

of credit supply at the exchange fairs (da Silva, 1959a, p.12). Tight money and credit market conditions persisted into the second half of 1568: A merchant letter dated August 25th 1568 continues to diagnose the Iberian peninsula with a deficiency in money and credit supply (da Silva, 1959b, p.22). One year after another disaster in 1591, Simón Ruiz – one of the wealthiest merchants of his time – wrote a letter to one of his factors instructing him to use money parsimoniously and instead use bills of exchange for payment whenever possible. This suggests that the wealthiest merchants still had access to credit instruments which they could use to bridge the money shortage (Martín, 1965, p.xiv). The sensitivity of Spanish financial markets to American silver arrivals is further evidenced by the severe effects that mere delays in silver shipments could develop (Pike, 1966, p.87). A Sevillian merchant's letter from November 25th 1553 laments such a delay, and states that the only credit still available came with a 60% annualized interest rate (Lockhart et al., 1976, pp.91ff.).

In sum, disruptions to Spanish money inflows from America resulted in a credit crunch.[34] This tightening was reflected in a 1 to 2 percentage point increase in lending rates that persisted for three years.[35] Accounts from contemporary merchant letters

[34]This picture is echoed in the historical literature. Morineau (1985, p.69) describes how the loss of the 1622 fleet sparked panic in Seville. More recently, the empirical evidence presented by Schularick, ter Steege, and Ward (2021) highlights the potency of contractionary monetary shocks in triggering financial crises.

[35]Appendix A.3.3 explores the concern that in the aftermath of maritime disasters, bills of exchange prices reflected merchants' fears of currency debasement, rather than Spanish lending rate fluctuations. When we calculate lending rates from bill prices in a way that eliminates the devaluation risk component,

suggest that this lending rate response fails to reflect an initial breakdown in credit markets, during which credit became inaccessible to all but the wealthiest merchants.[36]

3.2.2 Price adjustment

A leading explanation for money non-neutrality is that prices fail to adjust to money supply changes. To which extent did prices adjust in early modern Spain?[37] Figure 5 shows that the aggregate Spanish price level reacts sluggishly to money supply shocks. Only after three years does the mean consumer price response fall to -1%. Even then, however, the IRF estimate is not statistically significant. This renders price rigidity a suspect in our search for the monetary transmission channels through which money supply shocks exerted their influence on the real economy.[38]

The historical literature describes two ways in which reduced money arrivals first met rigid prices to bring about a reduction in output. First, consumption decreased as households went through a period of belt-tightening in the aftermath of money losses. Pike (1966, pp.30ff.) describes the consumption of silks and embroidery that the arrival of money from America triggered. To the extent that goods prices failed to adjust to negative money shocks, households were likely to cut back on this consumption after maritime disasters. Second, Spain's manufacturing regions were an important destination for American money arrivals.[39] Maritime disaster losses brought this money flow to a

we find a similar lending rate response, with a peak of 3.5% one year after the shock, and a persistence of two years (Figure A.9).

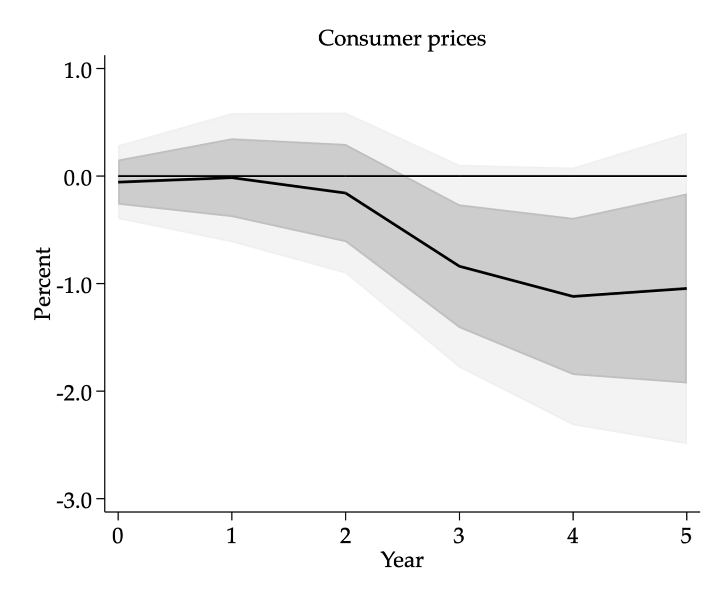
[36]These results speak to the literature that traces the origins of aggregate fluctuations back to the amplification of idiosyncratic shocks along an economy's input-output linkages (Gabaix, 2011; Acemoglu et al., 2012; Carvalho, 2014). Our results are particularly reminiscent of research that highlights sector specific financial frictions in the the propagation of shocks along production chains (Raddatz, 2010; Bigio and La'o, 2020; Costello, 2020; Luo, 2020; Demir et al., 2020; Altinoglu, 2021; Alfaro et al., 2021; Ghassibe, 2021). Viewed through an input-output network lens, negative money shocks to Spanish merchants could develop such a powerful effect throughout the Spanish economy, in part because merchants were located at a central node in Spain's early modern production network.

[37]One source of nominal price rigidity in early modern Spain were guilds. They were prevalent in the urban manufacturing and service sectors, but they also could be found in the primary sector, and among rural artisans (Ogilvie, 2011, p.19). As producers of differentiated products, guilds could set collective monopoly prices for the output of their members. If large enough, or if in possession of a chartered right to be the exclusive buyer of a particular industry's output (Ogilvie, 2011, p.33), guilds also could set price ceilings on the raw materials they purchased from their suppliers (Ogilvie, 2014).

[38]Appendix B.2 explores whether Spain's nominal adjustment was aided by a decrease in the silver content of Spanish coins. We find that such debasements played no role for the Castilian Maravedí, and at most played an auxiliary role for the Barcelona sous and the Valencian sous.

[39]Sevillian records from 1570 and 1571, which registered the outflow of American precious metals from their port of arrival together with their destination, identify Spain's manufacturing regions the second most important destination for American money arrivals. Only regions hosting important financial exchanges received more money (da Silva, 1965, p.67). Relatedly, Phillips (1987, p.540) states that part of the investment in the Spanish industrial sector was directly financed out of profits that were generated in the colonies.

Figure 5: Consumer price response to a negative 1 percentage point money inflow shock



Notes: Gray areas – 1 standard deviation and 90% confidence bands.

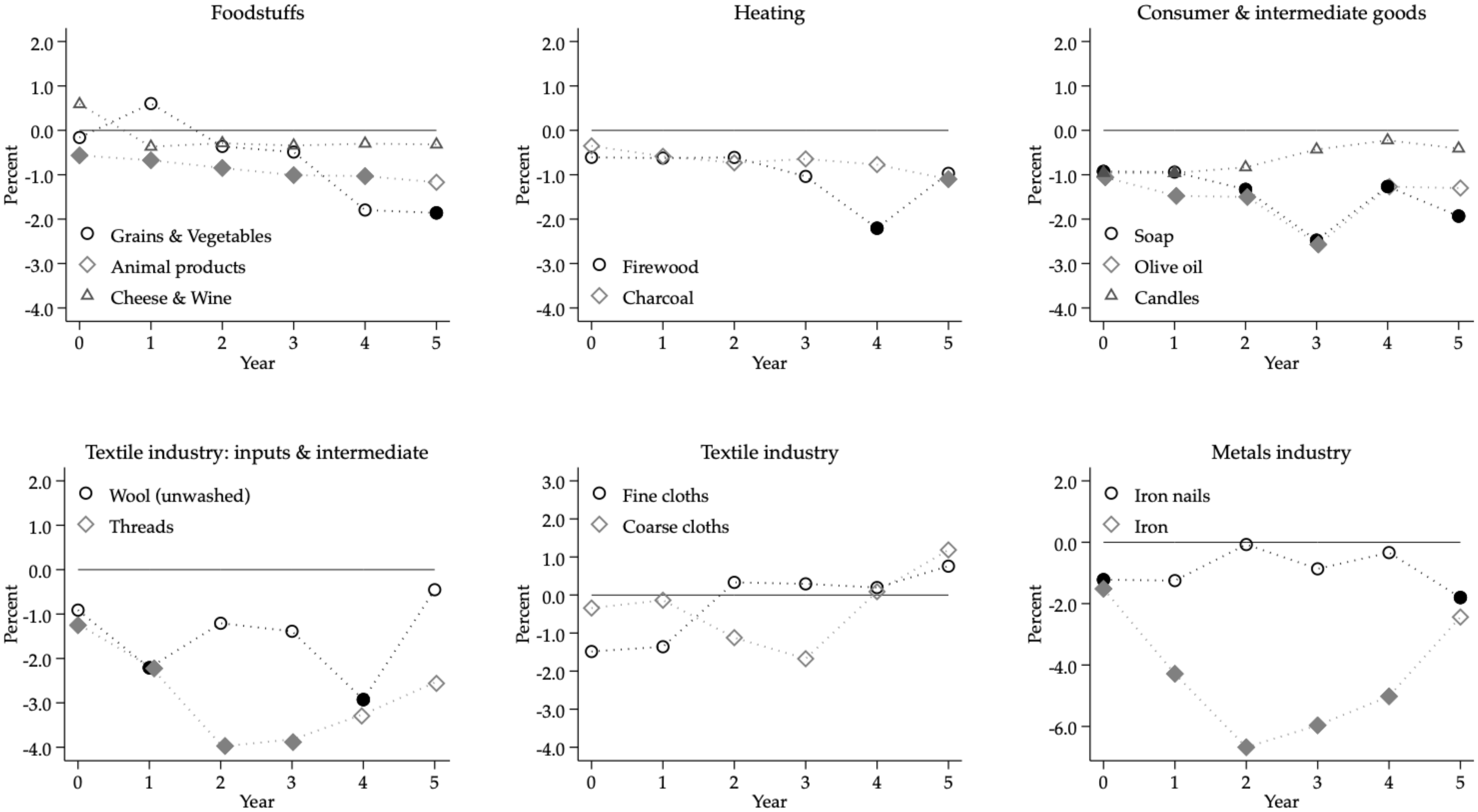
halt and thus disrupted the manufacturing industry's provision with money.[40] When prices for input goods failed to adjust sufficiently, liquidity constrained merchants and manufacturers had to reduce their purchase volumes.

To better understand the nominal adjustment of Spain's early modern economy we turn to the analysis of the disaggregated price data. We begin with the prices for essential consumer goods – food and heating. The top left panel in Figure 6 shows that most foodstuff prices decline slowly in response to a money shock. This is the case for essentials, such as grains and vegetables, as well as processed items, such as cheese and wine. The price reaction of these food items is furthermore statistically insignificant over much of the five-year horizon we analyze. Firewood and charcoal prices follow the same pattern (see top middle panel).[41] By contrast, prices for animal products – meats, eggs, and honey – fall immediately (see top left panel). The liquidation of livestock in response to a liquidity shortage described earlier presents one economic rationale for this. Even more disaggregated data reveals that the significant on-impact response is shared by mutton and beef prices (Figure B.1 in the Appendix).

[40]A merchant letter from September 5th, 1577 exemplifies this link between the arrival of American money and textile manufacturing investments. In this letter, Simón Ruiz instructs one of his factors to send the money arriving from America to him as soon as it arrives, so he can invest it in the production of woollen cloth (da Silva, 1959b, p.130).

[41]Note that the slow decline in prices for essential consumer goods may reflect stable demand rather than rigid prices. However, the slow adjustment of agricultural goods prices was accompanied by an immediate downward adjustment in the nominal wage for agricultural day laborers – a key input price to agricultural production (see section 3.2.3). Such an imperfect pass-through of input prices to output prices is indicative of price rigidity or time-varying markups (Rotemberg and Woodford, 1999).

Figure 6: Price responses to a negative 1 percentage point money inflow shock



Notes: Solid markers indicate significance at the 10% level.

The prices for nonessential consumer goods (soap, olive oil, and candles) fall quickly within the year of impact (see top right panel). The prices for soap and olive oil continue to fall for several more years. Both goods are not just consumer items, but also important intermediate inputs for the textile industry. They are required in large quantities to wash the wool, and to lubricate textile fibres for processing (García, 2007, p.183). The lower left panel of Figure 6 displays the price responses of two more textile industry inputs – unwashed wool and threads. Both prices fall substantially, but the wool price decline is somewhat less pronounced.[42]

In contrast to the textile industry's input prices, its output prices for coarse and fine cloths do not fall significantly. A similar divergence between input and output prices can be observed in metallurgy.[43] Whereas the iron price declines by a cumulative 6%, the price for nails only briefly falls by around 1%.[44] This input-output price divergence ties in with the notion that a credit crunch paralyzed merchant procurement of raw materials and intermediate inputs (see section 3.2.1). The imperfect pass-through of input prices to output prices is furthermore indicative of price rigidities in the manufacturing sector.[45]

3.2.3 Wage adjustment

Wages are another nominal variable, whose failure to adjust can give rise to money non-neutrality. The IRF estimate in Figure 7 shows that Spain's aggregate wage index immediately falls by around 1% in response to the negative money supply shock. Given the delayed response of consumer prices this implies an immediate real wage drop of 1%. This on-impact adjustment defies the common presumption that wages were more rigid than goods prices.[46] The following analysis of the disaggregated wage data traces the origins of early modern Spain's rapid nominal wage adjustment.

The upper left panel of Figure 8 isolates one occupational group that saw its wage drop markedly on impact: Unskilled agricultural laborers, such as harvesters. The rapidity of the nominal adjustment for this occupational group is perhaps not surprising given that unskilled agricultural labor was hired on a seasonal or even daily basis. Nevertheless,

[42]Wool was an important export item in early modern Spain. The relative stability of wool prices may thus reflect an initial increase in wool exports (see section B.1). In addition, the fire sale in livestock documented earlier reduced wool supply during the time it took the flock size to recover (see section 3.1).

[43]Gautier and Bihan (2020) and Pasten et al. (2020) make the related point that sectoral heterogeneity in price rigidity can amplify the real effects of monetary shocks.

[44]See de Gracia (2002) for a description of the putting-out system in Spain's early modern iron manufacturing sector.

[45]Note, however, that such imperfect pass-through of input prices to output prices can also result from endogenous markup fluctuations (Rotemberg and Woodford, 1999) and the repeated amplification of an initial liquidity shock along a production chain that is characterized by financial frictions (Bigio and La'o, 2020; Altinoglu, 2021).

[46]As our identification strategy exploits large shocks, our findings may reflect optimally timed wage changes in response to sizeable shocks as described by Golosov and Lucas (2007).

Figure 7: Nominal wage response to negative 1 ppt money inflow shock

Notes: Gray areas – 1 standard deviation and 90% confidence bands.

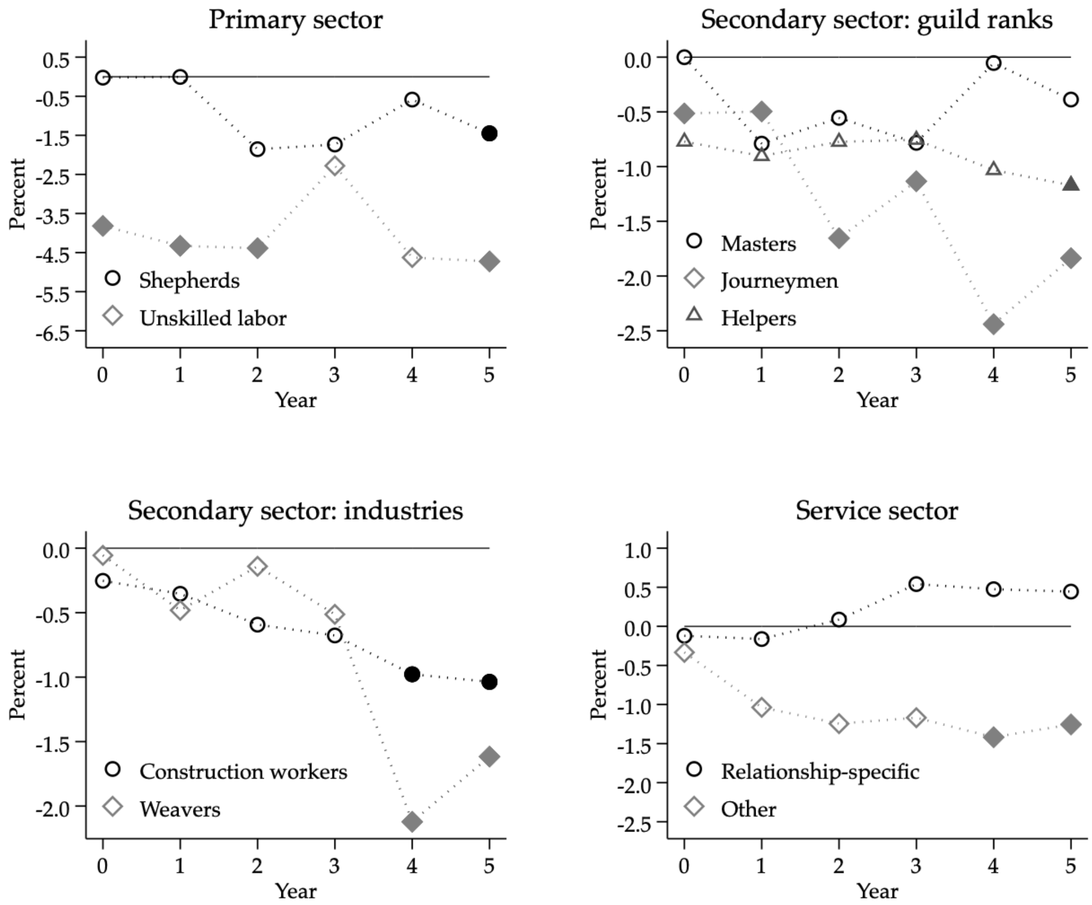
the magnitude of the wage drop stands out at 4%.[47] In contrast to the immediate wage drop among unskilled agricultural workers, the wages of skilled shepherds declined only gradually by around 1%.[48]

To a lesser extent, the contrast between skilled and unskilled wages is also echoed in the secondary sector. The upper right panel of Figure 8 displays the response of various occupations according to their guild rank. Skilled masters only experienced an insignificant wage decrease, whereas helpers, and especially journeymen saw their wages

[47]Absent a contraction in the consumption of agricultural goods (see section 3.1), agricultural labor demand presumably remained relatively stable in the face of money supply shocks. This suggests that the marked decline in the wage for unskilled agricultural workers reflects an increase in their supply. One snippet of data that is informative in this regard comes from the renovation records of the Royal Palace in Madrid. Hamilton (1947, p.208) provides an annual time series (1737–1800) on the number of different occupation types that were employed in this renovation project. This data offers us a rare glimpse into how employment flows responded to money supply shocks. Our IRF estimate suggests that this particular construction project right away released between 10% and 20% of the occupation types that were employed in it (Figure B.2 in the Appendix). Given that many of Madrid's construction workers originated form its rural surroundings, one plausible scenario is that the labor that was released from urban construction flowed back to the pool of unskilled agricultural laborers (Andrés Ucendo and Lanza García, 2014). Any release of labor from textile manufacturing was similarly prone to increase the supply of unskilled agricultural laborers. This is because many weavers were rural peasants who supplemented their incomes through manufacturing jobs (García Sanz, 1977, p.224). In fact, many of the early production stages of textile manufacturing were deliberately outsourced to rural areas by merchants intent on avoiding the guild regulations prevalent in cities (Montañés, 2012; Montemayor, 1996, p.228).

[48]Shepherding is categorized as a skilled occupation because it involved important decision making. For example, the timing of herd movements affected the quality of the sheeps' wool. Knowledge of the terrain and meteorology were advantageous. The occupation also involved financial decision making connected with the continued supply of the transhumant herd with necessary inputs, such as salt.

Figure 8: Nominal wage responses to negative 1 ppt money inflow shock



Notes: Solid markers indicate significance at the 10% level.

decline more markedly. Reminiscent of more recent findings, monetary contractions in early modern Spain thus aggravated inequality by widening the wage gap between skilled and unskilled workers (Carpenter and Rodgers III, 2004; Coibion et al., 2017). The guild rank results suggest that differences in wage responses were in part driven by institutional factors. Masters, for example, typically shared in the wage setting power of their guilds, whereas journeymen and helpers were more likely to be wage takers with little collective bargaining power.

We find no evidence indicating that secondary sector wage responses differed across industries: the gradual wage decline among weavers resembles the gradual wage decline among construction workers (see lower left panel of Figure 8). Thus, secondary sector wages as a whole exhibit a rather gradual adjustment to money supply shocks. Given that labor is a key input into the secondary sector's production process, the failure of nominal wages to immediately adjust implies that liquidity constrained merchants could employ less labor in their production networks.

One group of jobs whose nominal wage rate remains entirely unaffected by the monetary contraction are relationship-specific service sector jobs. This covers occupations that build on mutual trust (e.g. doormen, stewards) and occupations that are characterized by the accumulation of relationship-specific knowledge (e.g. bookkeepers). By contrast, other service sector occupations (e.g. basket emptiers, cart-loaders) see their wage rates decline gradually by around 1%.

In sum, the flexibility in Spain's aggregate wage level was primarily underpinned by instantaneous wage adjustments among unskilled agricultural workers. Wage adjustments in the secondary and tertiary sectors were more gradual, possibly contributing to a decline in output there.

3.3. Correlated shocks

We now turn to the discussion of the non-monetary losses and fiscal losses that were associated with maritime disasters. Both can be viewed as correlated shocks that could interfere with our identification strategy. In this section we show that neither can account for the response of Spain's economy to maritime disaster events, suggesting that our IRF estimates indeed describe monetary effects.

3.3.1 The Crown's finances and sovereign risk

Although 85 to 95% of precious metal inflows from the colonies were privately owned (García-Baquero González, 2003; Costa et al., forthcoming), the remainder nevertheless could constitute an important source of revenue for the Crown.[49] In the first half of the 16th century only 4% to 10% of crown revenues derived from American precious metals. Under Phillip II this figure rose up to 20%. In the 17th century, the share of American precious metals in crown revenues wanes again to around 11% (Ulloa, 1977; Drelichman and Voth, 2010; Comín and Yun-Casalilla, 2012; Álvarez-Nogal and Chamley, 2014). Thus, the loss of silver in maritime disasters could put stress on the Crown's finances, making a sovereign debt crisis more likely.

The Royal Treasury's revenues and expenditures were small compared to the Spanish economy – on average 3% between 1555 and 1596, and around 5% at the end of our sample (Ulloa, 1977; Drelichman and Voth, 2010; Barbier and Klein, 1981). Furthermore, a substantial share of this was not spent in Spain, but for military purposes abroad.

[49] Only in the late 18th century does the Royal Treasuries' share of precious metal remittances increase to above 20%. Occasionally, however, the Crown sequestered part of the privately owned treasure through forced loans that were reimbursed later with additional interest (Sardone, 2019).

Table 2: Sovereign debt crises and maritime disasters

Debt crisis year	1557	1560	1575	1596	1607	1627	1647	1652	1662	1686	1700
Nearest disaster year	1555	1555	1567	1591	1605	1624	1641	1641	1656	1682	1698
Distance (in years)	2*	5*	8	5*	2*	3*	6	11	6	4*	2*

Notes: ⋆ indicates sovereign debt crises that occurred within five years after a maritime disaster. Sovereign debt crisis years from Pike (1966), Artola (1982), Homer and Sylla (1991), Álvarez-Nogal (2003), Reinhart and Rogoff (2009), and Álvarez-Nogal and Chamley (2014).

Together with the fact that the Crown's silver revenues amounted to no more than one fifth of all government revenues, this suggests that maritime disasters only had a small direct effect on government spending within Spain.

Maritime disasters, however, could indirectly affect government spending, by raising the spectre of default and spooking the Spanish Crown's creditors. Despite its small public sector share, the Spanish public debt-to-GDP ratio was large – at times exceeding 50% according to Álvarez-Nogal and Chamley (2014).[50] Sovereign debt crises therefore might have negatively affected the Spanish economy through a reduction in public debt holder wealth. It is important to note, however, that during sovereign debt crises not all debt was written down. In fact, actual debt write-downs may have been quite small (Álvarez-Nogal and Chamley, 2014).

We analyze whether the real effects of money losses were the consequence of a monetary transmission through the Crown's finances in two steps. First, to see whether maritime disasters provoked sovereign debt crises, Table 2 lists the dates of sovereign defaults, together with the closest preceding maritime disaster date. Indeed, seven out of the eleven sovereign debt crises in our sample occurred within five years after a maritime disaster. However, this also implies that 26 maritime disaster years were not followed by a sovereign debt crisis.

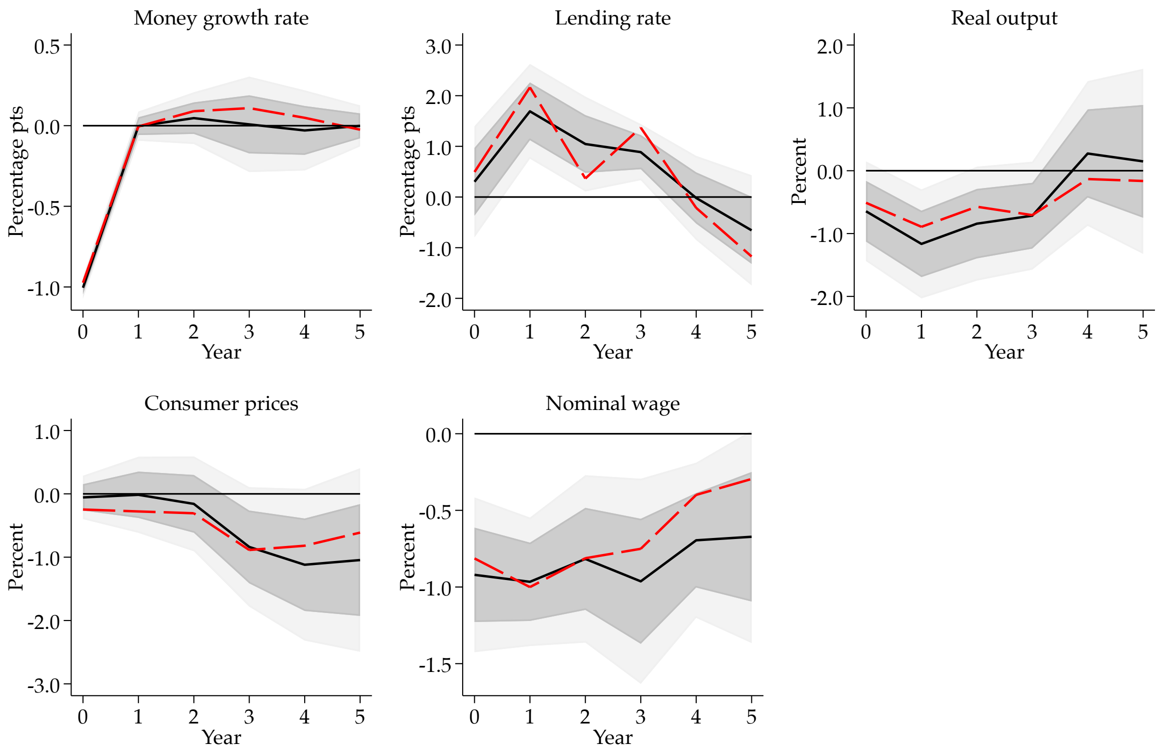
Second, to analyze the extent to which the money non-neutrality result is driven by these seven sovereign debt crises we re-estimate our baseline IRFs with an adjusted specification, which allows money losses to develop different effects on the economy if they are followed by a sovereign debt crisis. In particular, we amend the baseline specification from section 2.4 in the following way:

$$(Y_{t+h} - Y_{t-1})/Y_{t-1} = \alpha_h + \beta_h S_t + \delta_h S_t * C_t + \eta_h C_t + \gamma_h X_t + u_{t+h},$$

where C_t is a binary indicator that equals 0 except in sovereign debt crisis years and the preceding five years. This purges sovereign debt crisis effects over the full five year horizon over which the IRF extends. Figure 9 shows that the adjusted IRFs closely resemble the

[50]Accordingly, debt servicing costs used up a large part of government revenues.

Figure 9: Debt crises: Responses to negative 1 percentage point money inflow shock

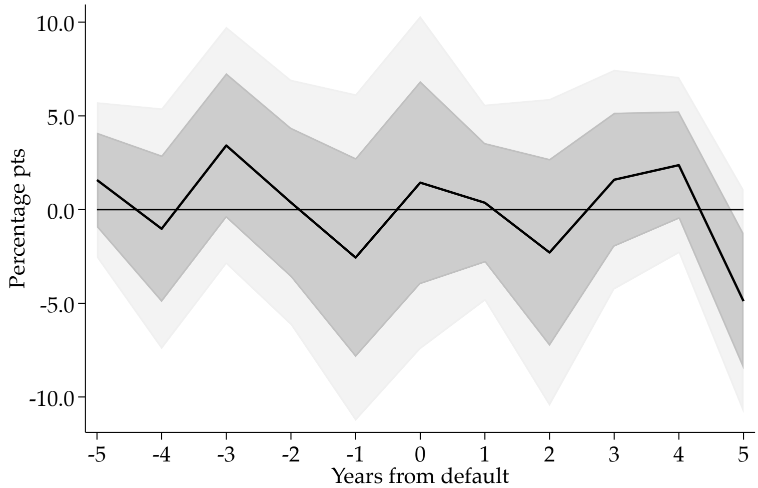


Notes: Solid black line – baseline specification. Dashed red line – specification controlling for separate effect of sovereign debt crises. Gray areas – 1 standard deviation and 90% confidence bands.

baseline IRFs, indicating that the real effects of money supply shocks did not significantly differ according to whether or not they were associated with sovereign debt crises. Thus, the Crown's finances do not appear to have played a major role in the transmission of money supply shocks.

Another way in which the Crown's finances could drive our non-neutrality result is if private sector lending rates were influenced by sovereign risk. This is often the case today, where private sector credit conditions are tied to sovereign credit worthiness, and sovereign bond rates act as a baseline for private sector interest rates (CGFS, 2011; IMF, 2013; Bocola, 2016). In pre-modern economies, however, private interest rates typically were lower than public rates, as lending to monarchs was considered to be more risky (de Mercado, 1587; Henriques and Palma, 2020, p.307). To see whether private sector lending rates in our sample were affected by sovereign risk, we analyze the behavior of the lending rate series around sovereign default dates. To this end, Figure 10 shows average annual lending rate changes in the -5 to +5 year window around sovereign default years. We find little indication that lending rates budged either in the up-run or the aftermath of a sovereign default. Overall, we find no evidence to suggest that the Crown's public

Figure 10: Lending rates around sovereign defaults



Notes: Solid black line – mean estimate of annual lending rate change. Gray areas – 1 standard deviation and 90% confidence bands. Average lending rate changes from 0 to +5 are based on a forward projection equivalent to baseline specification (eq. 1), but replacing the money loss regressors with a binary sovereign default indicator. Lending rate changes from -1 to -5 are based on a symmetric backward projection.

finances were an important mediator along the causal chain that translated money losses into real output effects.

3.3.2 Non-monetary wealth

The maritime disasters that resulted in money losses also entailed the loss of non-monetary wealth, such as ships. In this section we document that non-monetary losses were small compared to the monetary ones. Table 3 provides estimates of the value of the non-monetary wealth loss associated with maritime disasters. In each of the 33 maritime disaster years between 1 and 30 ships were lost. The resale value for ships lay in the 1600 to 8000 peso range (Carrasco González, 1996, p.156).[51] Using the lower value, this implies that even in the maritime disaster with the largest number of ships lost, the overall ship wealth loss amounted to no more than 0.9% of the precious metal loss. For the high re-sale value of 8000 pesos, the corresponding fraction is 4.5%. The 4.5% value, however, corresponds to an outlier event in which 30 ships were lost, whereas the median ship value loss in our sample amounts to 0.8% of the precious metal loss – even for the high-ship value scenario.[52]

[51] Few ships made more than four transatlantic return voyages. After that, they often were sold and used in calmer waters (Carrasco González, 1996, p.156). Repairing and outfitting worn out ships after a long-distance voyage cost nearly as much as buying a new ship (Gelderblom et al., 2013).

[52] The majority of vessels in the Atlantic had less than 400 tonnes capacity (Carrasco González, 1996, p.157). However, ships carrying the treasure often were from the military squadron that protected the fleets – two to six military ships with a larger tonnage. Such large ships were more expensive to build.

Table 3: Value of non-precious metal losses

Precious metal share	Ship loss	Ship value		Life loss	
(% of import value)	(per disaster)	Low	High	Low	High
Until late C18th:	1 to 30	*Pesos per ship:*		*Crew per 100t ship:*	
80%	(median=3)	1600	8000	30	100
From late C18th:		*Percent of metal loss:*		*Percent of labor:*	
> 55%		<0.9%	<4.5%	<0.09%	<0.3%

Sources: Precious metal import share from Fisher (1985), García-Baquero González (2003), and Cuenca-Esteban (2008). Ship values from Carrasco González (1996, p.156). The ship values are resale values that reflect ship depreciation. *Crew per ship*: Crew per 100 tonnes from de Vries (2003), quinquennial data on average ship tonnage from Phillips (1990). *Percent of labor*: Population data from Álvarez-Nogal and Prados de la Escosura (2013). Working-age (16-50) fraction (49.6%) from 1787 census described in Martín (2005).

The amount of lives lost as a fraction of the Spanish working population was small, never amounting to more than 0.3%, even when large numbers of ships sank, and even when assuming very large crews. For more moderate crew size estimates and median ship loss numbers this fraction is negligibly small.

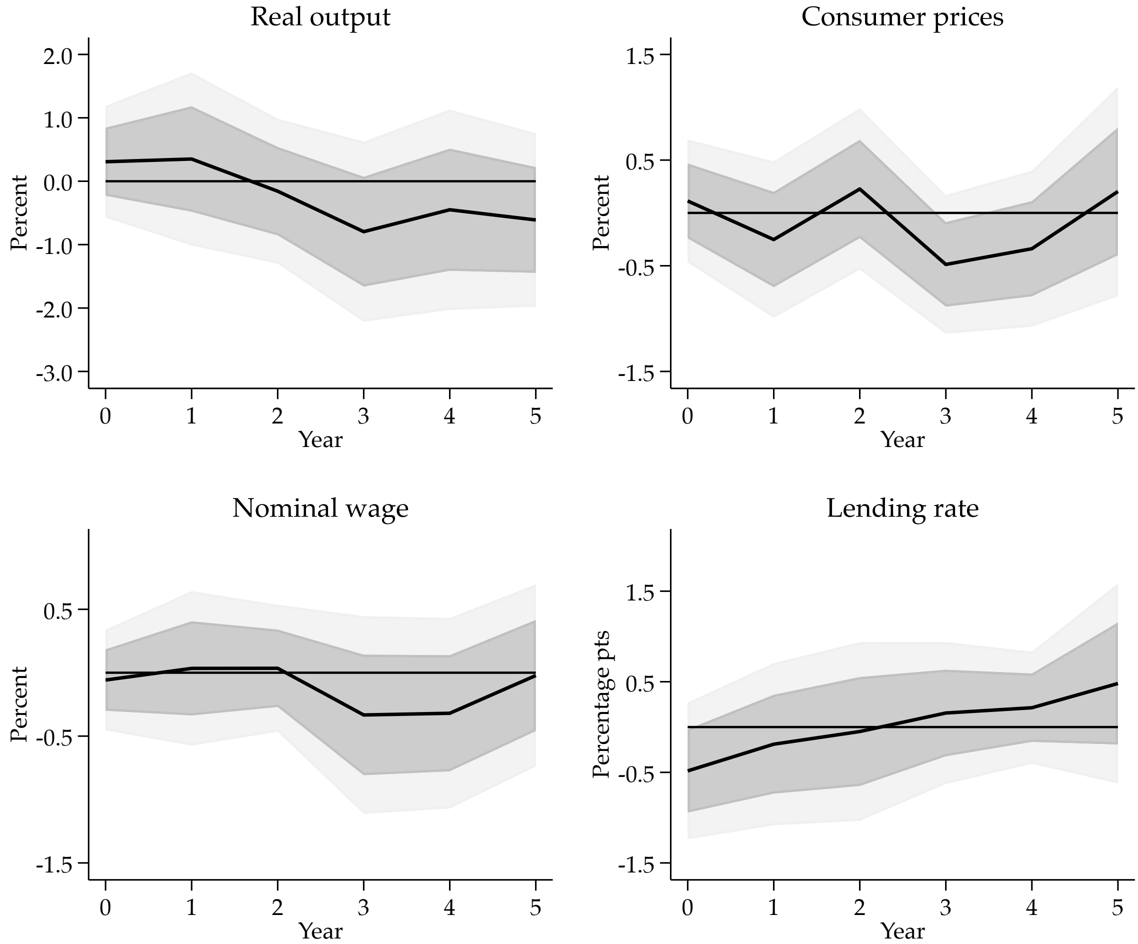
Precious metals comprised 80% of the total value of imports up to the late 18th century (García-Baquero González, 2003; Fisher, 2003). Only in the late 18th century did the share of non-metal colonial goods – such as tobacco, cacao, and sugar – increase significantly above 20%. Fisher (2003) documents that between 1782 and 1796 43.6% of the value of the commodities imported into Barcelona and Cádiz pertained to non-metal colonial goods. To address the concern that at the end of our sample the monetary shock measure becomes diluted with a non-monetary wealth shock, we conduct a subsample analysis in which we end our sample in 1780. The results are very similar (Figure B.11 in the Appendix).

Finally, we use maritime disasters on outbound voyages from Spain to America to assess the economic impact of non-monetary maritime disasters on the Spanish economy.[53] Maritime disasters on outbound voyages led to similar non-monetary losses as maritime

Phillips (2007) documents the construction costs for two such 1000 tonne ships in the late 17th century. Building them anew cost 63,419 pesos. Assuming a resale value of 20,000 for such ships, and assuming all sinking ships are of this type, the median value of ship losses across disaster events would add up to 1.9% of the value of the precious metal loss.

[53]Most sources that provide historical accounts of maritime disasters on inbound voyages also do so for outbound voyages. In particular we use Marx (1987), Walton (1994), and the primary archival data from `todoavante.es`. We apply the same dating convention as for the inbound disaster shocks, i.e. we assume news about a maritime disaster takes time to travel to Europe.

Figure 11: Economic effects of maritime disasters on outbound voyage, per loss of 1 ship



Notes: Solid black line – mean IRF. Gray areas – 1 standard deviation and 90% confidence bands. The graph shows IRFs estimated on the basis of baseline specification 1 augmented by an indicator of the number of ships lost on outbound voyages.

disasters on inbound voyages. The key difference is that maritime disasters on the outbound voyage did not result in the loss of large quantities of money. Between 1531 and 1810, we record 14 instances of outbound fleet voyages that ended in disaster. The number of ships lost in such events ranged from 1 to 16. In the large events more than a thousand lives and cargo worth more than 2 million pesos was lost (equivalent in value to around 51 tonnes of silver). Despite this, Figure 11 shows that these events did not leave their mark on aggregate Spanish economic variables. Neither output, prices, wages, nor interest rates responded to the loss of lives, ships, and cargo on outbound shipments. This supports the interpretation of inbound maritime disaster IRFs as monetary effects.[54]

[54]This finding also constitutes prima facie evidence against an independent effect of several psychological forces that could have been triggered by maritime disaster events (e.g. a downturn in economic sentiment driven by superstition or the mourning about relatives lost at sea).

4. Conclusion

In this paper we use a series of natural experiments to identify the causal effects that run from the monetary side of the economy to the real side. Maritime disasters in the Spanish Empire repeatedly gave rise to large losses of monetary metals. The causes of these disasters had nothing to do with the economy in Spain, and the corresponding precious metal losses therefore resulted in exogenous variation in the Spanish money supply.

This paper contributes to a long-standing debate in economics that already took place among contemporaries witnessing the influx of American precious metals into Europe. In 16th century Spain, theologians expressed the idea that an increase in money is absorbed by an equivalent increase in prices (de Azpilcueta, 1556; de Molina, 1597). Only a few decades later, English mercantilists hypothesized about the non-neutrality of money. They argued that an increase in money not only increases prices, but stimulates real economic activity (Misselden, 1622; de Malynes, 1623). Our findings lend support to the latters' hypothesis.

Negative shocks to Spain's money supply caused real output to decline. The output decline was particularly large and persistent in textile manufacturing. Lending rate data and merchant letters indicate that production contracted against the backdrop of a credit crunch, which negatively affected merchants' ability to raise the working capital necessary to supply input goods for their producers. Delays in the adjustment of prices furthermore weighed on the amount of goods that were transacted.

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Appendix

to *"The vagaries of the sea: evidence on the real effects of money from maritime disasters in the Spanish Empire"*

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Contents

A. Data

A.1. Precious metal losses

Selection of maritime disasters, losses, and salvaging

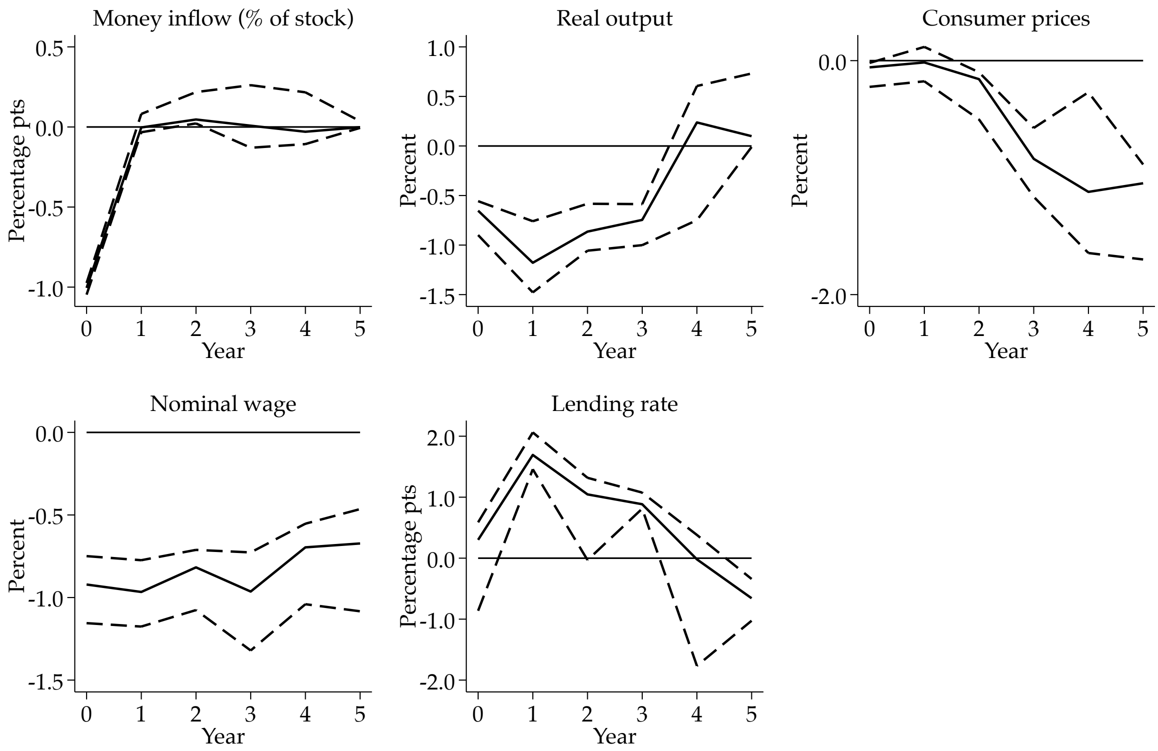
Our selection of precious metal losses is based on an extensive review of the existing literature on maritime disasters in the Spanish Empire. Table A.1 presents an overview of sources. We include only precious metal shipments that were bound for Spain. As a consequence, all but one of the maritime disasters listed in Table A.1 took place in the Atlantic Ocean. The only exception is the sinking of the Santa Leocadia, which in 1800 carried precious metals from Peru to Panama. While 130,000 pesos of its treasure constituted a fiscal transfer between Spanish American colonies, the remainder was to be transported over the Isthmus of Panama and loaded onto ships destined for Spain.

While our sample of maritime disasters includes all known major events, we are likely to miss some incidents in which small individual merchant vessels sank with an unregistered amount of coins. The precious metal loss associated with these must have been small to escape widespread public attention. Our sample contains some such small disaster events which illustrate the type of losses that could have escaped widespread notice. For example, the 1550 wreck of the merchant caravel *Santa Maria de la Piedad* near Terceira Island (Azores) added around 100,000 pesos ($\approx$ 2.5 tonnes) to the loss for that year.

To address the sensitivity of our results with respect to the selection of maritime disaster events, we calculate impulse response functions based on subsets of our maritime disaster list. Each subset leaves out three random disaster events. The resulting range of IRF estimates depicted in Figure A.1 shows that the baseline results' characteristics are robust to the exact selection of disaster events.

Our analysis accounts for salvaging. How quickly precious metals could be salvaged depended on the accessibility of the sunken ship. When a ship sank in shallow waters, its treasure was accessible to divers and could thus be quickly salvaged. When sunken treasure was salvaged within weeks after the disaster event we do not include it in our loss series (e.g. the 1711 Nueva España fleet), nor do we include such immediate salvaging into our salvage series. Many salvaging operations, however, lasted longer, because shipwrecks first had to be dragged to more shallow waters, or because bad weather denied the salvaging party access to the wreck site. As soon as salvaging operations dragged on for several months we include the associated disasters' losses into the loss series, and the subsequently salvaged amounts into the salvage series. Few salvaging operations lasted more than a year, because shifting sands commonly hindered further salvaging efforts

Figure A.1: Disaster subsets: negative 1 percentage point money inflow shock



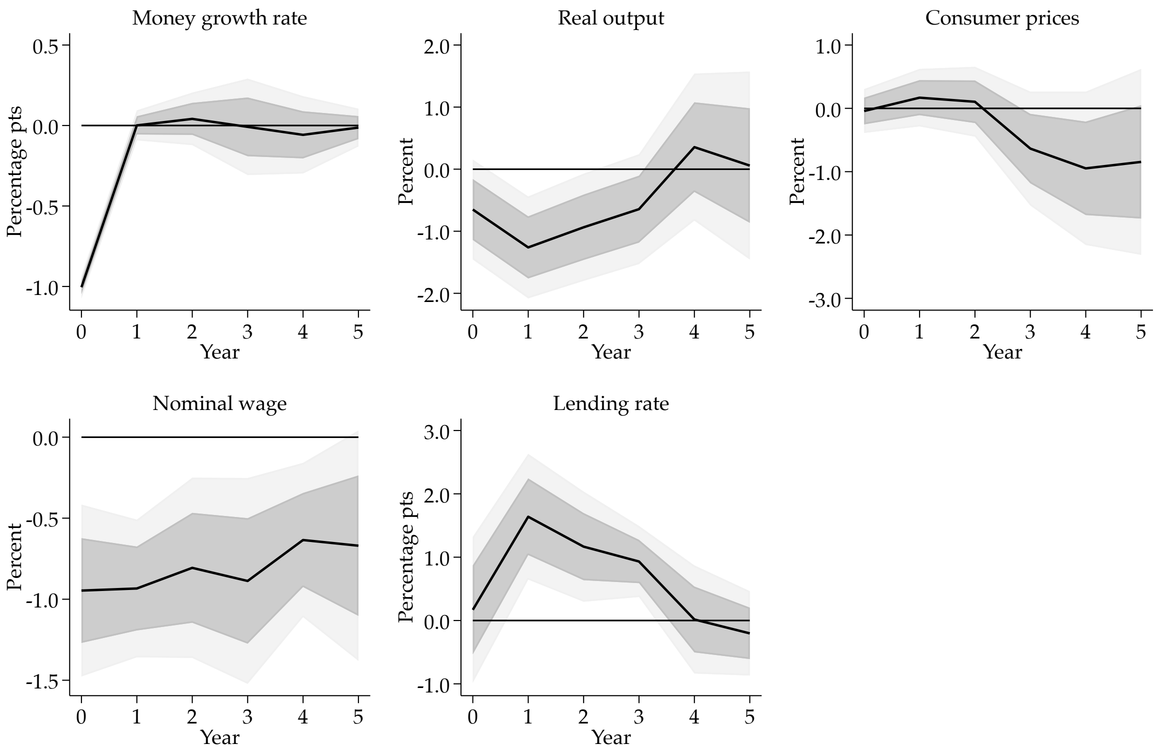
Notes: Solid line – full sample response. Gray area – 1st to 99th percentile (pointwise) IRF range based on 100 disaster subsets, each leaving out three disasters.

(Chen et al., 2021, p.4). Salvaged precious metals were typically transported to Spain on board of the following year's treasure fleet (Walton, 1994, p.166). In our baseline analysis the first lag of the salvage variable thus controls for the effect of the arrival of salvaged precious metals on the Spanish outcome variables of interest.[5]

We are aware of two maritime disaster events for which salvaging operations extended beyond one year. First, the salvaging of the 1715 loss lasted until 1718. The return of successive salvaging operations, however, declined rapidly (Peterson, 1975, p.369). Second, Potter (1972, p.219) describes the repeated salvaging operations that took place after the 1656 disaster until shifting sands eventually also frustrated this effort (Marx, 1987,

[5]To the extent that actually salvaged amounts did not coincide with merchants' expectations thereof, the year after a maritime disaster shock could give rise to a secondary salvaging news shock. This expectation error is not accounted for in the baseline specification, whose disaster loss and salvaging regressors only account for the actually realized net loss. In principle, this could give rise to an omitted variables problem (the expectation error is omitted) and a measurement error problem (ex ante expected net losses are confounded with ex post realized net losses). On both accounts, however, the large variance of the loss measure limits bias (see the next section for quantitative measurement error examples). Also, the salvaging expectation error was likely to be moderate because uncertainty about the amount of treasure that could be salvaged was largely determined by a shipwreck's location. The location in turn was either known, in which case salvaging operations were undertaken, or not, in which case no salvaging occurred.

Figure A.2: Impulse responses for negative 1 ppt money inflow shock (long salvaging)



Notes: Results based on specification that separately controls for the amount of salvaged precious metals from the 1656 and 1715 wreck sites. In both cases, salvaging operations extended beyond one year.

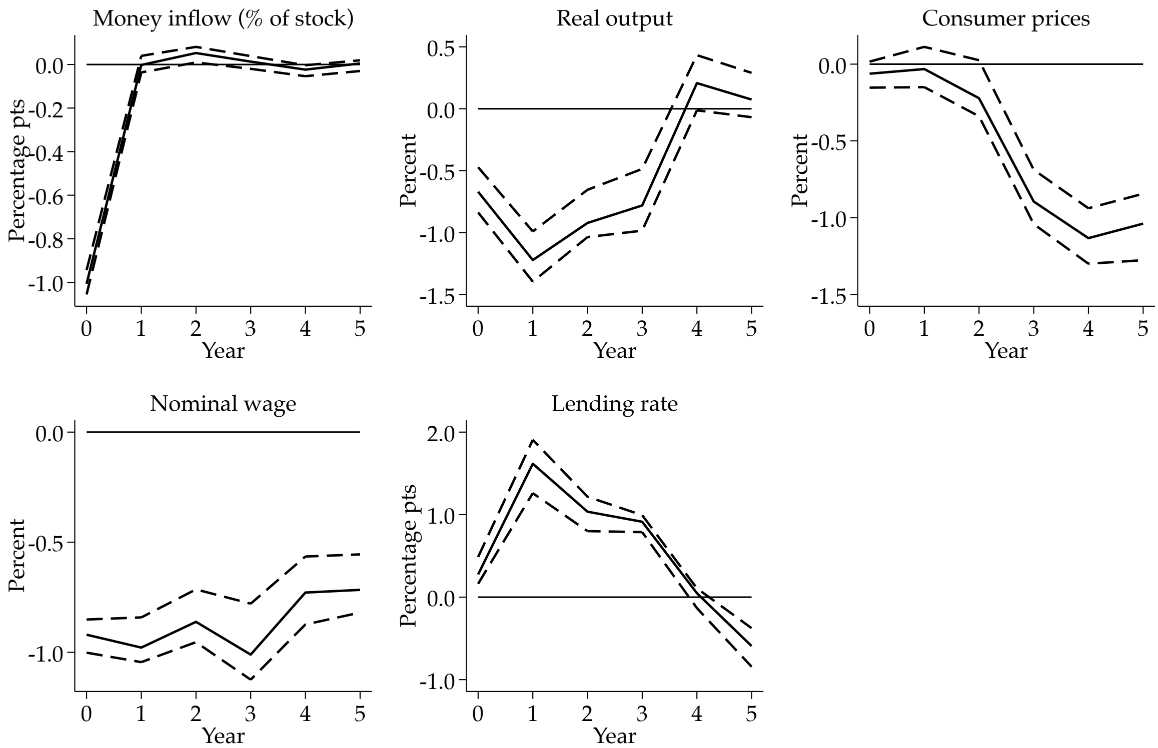
p.316). Our baseline analysis does not account for the additional delay in the arrival of the salvaged precious metals associated with the maritime disasters of 1656 and 1715. Figure A.2, however, shows that the baseline results are robust to adding separate controls for the amounts salvaged in the aftermath of these two more protracted events.

Smuggling and measurement error

Because private treasure flows were taxed upon arrival in Spain there existed an incentive to not register them. The data collected by Mangas (1989, p.316) and Morineau (1985, pp.242 and 375) suggests that, on average, smuggling amounted to 30% of registered shipments in the 16th century, 67% in the 17th century, and 47% in the 18th century. We apply these smuggling shares whenever no better information on treasure size is available (e.g. due to a complete salvaging of the treasure at a later time). The smuggling rate's standard deviation equals 7 percentage points (according to 27 observations for the 17th century (Mangas, 1989)). Given an average inflow-to-stock ratio of 9% this translates into a 0.63 percentage point standard error for the inflow shock measure.

While the appropriate non-classical measurement error case is reported in the next

Figure A.3: Smuggling error: negative 1 percentage point money inflow shock



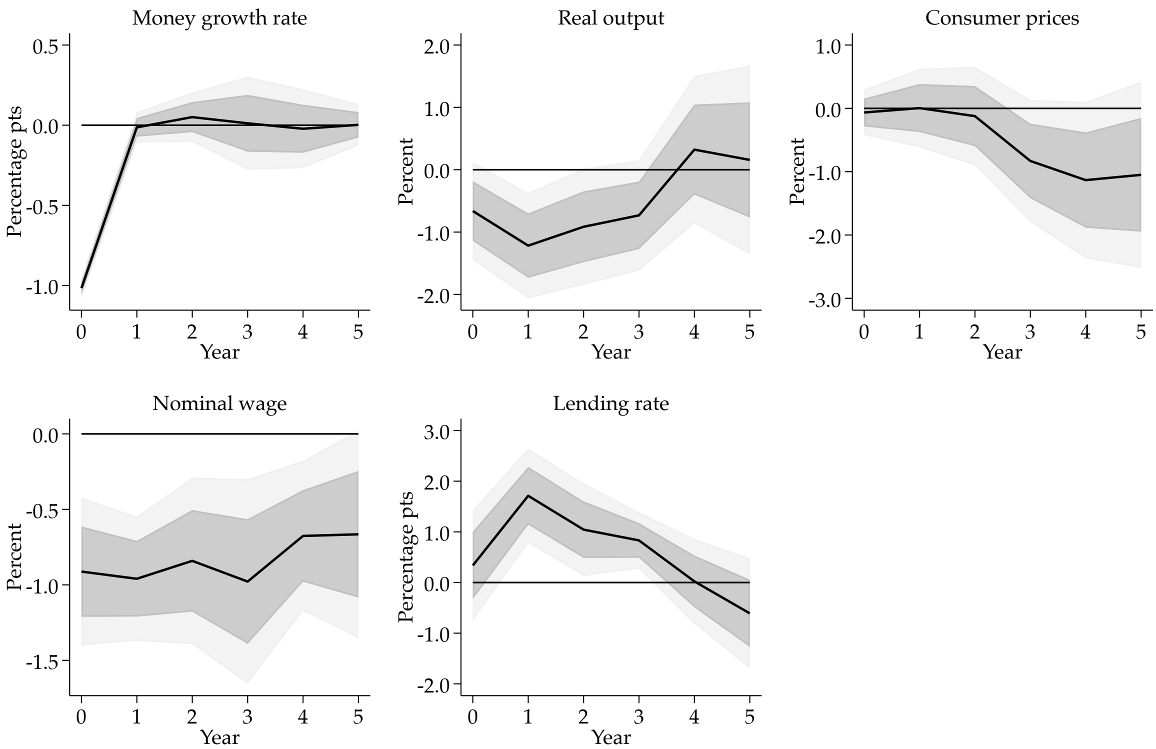
Notes: Solid line – baseline IRFs. Dashed lines – min-max IRF range calculated from 100 shock series with random error term added to non-zero shock values. Error term $\sim \mathcal{N}(0, 0.63^2)$.

paragraph, the magnitudes involved can be more transparently laid out with classical measurement error calculus. The variance in the shock measure equals 13.56 ($= \sigma_x^2$). The standard deviation of the measurement error that derives from uncertain smuggling rates amounts to 0.63 percentage points. Given that only 33 out of our 280 sample years (12%) had maritime disasters and thus were affected by the measurement error, this implies a measurement error variance, σ_u^2, of 0.0057 ($= 0.12^2 \cdot 0.63^2$). For these quantities, the classical attenuation factor, $-\frac{\sigma_u^2}{\sigma_u^2+\sigma_x^2}$, amounts to just -0.04%. Put differently, because identification largely rests on the difference between large losses in disaster years and zero losses in non-disaster years, the 0.63 percentage point standard deviation error in the shock measure does not matter much.[6]

To cover the non-classical measurement error case, we add a random error term to each non-zero shock measure. The random term is centered around 0 and has a standard deviation of 0.63 percentage points – corresponding to the 0.63 percentage point standard

[6]This assumes that measurement error is zero for non-disaster years. In light of the above discussion of the incomplete coverage of small disaster events this might be an exaggeration. Assuming non-disaster years are afflicted by the same measurement error as disaster years results in a still small attenuation factor of -4%.

Figure A.4: Excluding 1591 disaster: negative 1 percentage point money inflow shock



deviation in the money inflow-to-stock ratio implied by the smuggling rates reported in Mangas (1989). We then calculate 100 different IRFs based on 100 shock series with random errors added. The distance between the resulting IRF range and the baseline IRF estimate conveys an idea of the magnitude of the bias that this measurement error can generate. The resulting IRF range depicted in Figure A.3 confirms that any bias resulting from the smuggling derived measurement error is small.

The maritime disasters in 1591 does not lend itself to the standard treatment described above. This is because it is not associated with the loss of any officially registered precious metals. However, according to Walton (1994) the multiple shipwrecks of this year led to the loss of 10 million pesos. This is the figure we use in our baseline analysis. The size of this loss may in part be explained by the hibernation of the previous year's fleet in Havanna. The 1591 fleet thus likely carried more than one year's worth of unregistered treasure. Nevertheless, because of the uncertainty which the 1591 losses are shrouded in, we also conduct a robustness check in which we exclude this event from the analysis. Figure A.4 shows that our results are robust to the exclusion of this event.

Table A.1: Maritime disasters

Year	Source	Silver equivalent	Notes
1537	Walton (1994, p.24)[1]	18,258 kg	around 500,000 pesos captured
1550	Potter (1972, pp.215,299)	8,079 kg	more than 300,000 pesos sunken
1554	Walton (1994, p.61)	73,031 kg	almost 3 million pesos in treasure sunken, about half salvaged
1555	Potter (1972, p.160), Bonifacio (2010)	12,780 kg	500,000 pesos sunken
1563	Earle (2007, pp.9ff.), Bonifacio (2010)	24,430 kg	around 1 million pesos sunken
1567	Walton (1994, p.61)	109,547 kg	more than 4 million pesos sunken; salvaging failed
1591	Walton (1994, p.83)	255,610 kg	10 million pesos sunken; about 3/4 salvaged
1605	Walton (1994, pp.83-84)[2]	204,488 kg	8 million pesos sunken; salvaging failed
1621	Marx (1987, p.302.)	382 kg	around 15,000 pesos in treasure sunken; most of it salvaged
1622	Potter (1972, pp.215ff.), Marx (1987, pp.200ff.)	188,951 kg	more than 7 million pesos in treasure sunken; partly salvaged
1623	Marx (1987, p.202)	76,345 kg	about 3 million pesos sunken
1624	Mangas (1989, p.318)	51,122 kg	2 million pesos sunken
1628	Potter (1972, p.160), Marx (1987, p.248)	30,538 kg	around 1.2 million pesos sunken, largely salvaged
1628	Venema (2010, p.213)	80,660 kg	177,000 pounds of silver and 66 pounds of gold captured
1631	Marx (1987, p.424)	58,169 kg	more than 2 million pesos sunken; 1 million pesos salvaged
1631	Marx (1987, p.249)	150,241 kg	more than 5.5 million pesos sunken; very little salvaged
1634	Sandz and Marx (2001, p.129)	7,635 kg	around 300,000 pesos in treasure sunken, partly salvaged
1641	Mangas (1989, p.318)	76,683 kg	3 million pesos sunken
1654	Earle (2007, p.83)	255,610 kg	10 million pesos sunken; 3.5 million pesos recovered
1656	Potter (1972, p.432)	173,815 kg	2 million pesos captured; around 5 million pesos sunken
1656	Walton (1994, pp.128, 140)	127,805 kg	5 million pesos sunken, 2.5 million pesos salvaged
1682	Bueno (1996, p.84)	153,366 kg	6 million pesos sunken
1698	`www.todoavante.es`	161,540 kg	around 6.5 million pesos sunken, 6 million pesos salvaged
1702	Kamen (1966)	7,350 kg	around 80,000 pesos captured and sunken by British and Dutch
1708	Phillips (2007, pp.46,181), Sedgwick (1970)[3]	286,283 kg	11 million pesos sunken and 200,000 pesos captured

1715	Marx (1987, p.431)	309,972 kg	12 million pesos sunken; around 5 million salvaged
1730	Walton (1994, p.166)	139,556 kg	more than 5.5 million pesos sunken; partly salvaged
1733	Fine (2006, p.153)	311,908 kg	around 12.5 million pesos sunken; almost all salvaged
1750	Putley (2000), Amrhein (2007, ch.1)[4]	10,321 kg	272,000 pesos sunken; 14,467 pesos salvaged; 144,000 pesos captured
1752	Marx (1987, p.443)	49,620 kg	2 million pesos sunken, mostly salvaged
1753	Marx (1987, p.443)	38,134 kg	1.5 million pesos sunken
1762	The Gentleman's and London Magazine (1763, p.528)	62,895 kg	Around 2.5 million pesos captured
1786	Potter (1972, pp.349ff.)	185,716 kg	7.5 million pesos sunken, mostly salvaged
1800	Bravo (2010)	51,264 kg	Around 2 million pesos sunken; partly salvaged
1802	Sandz and Marx (2001, p.218)	13,742 kg	Around 0.5 million pesos sunken
1804	Cobbett (1804, p.663)	113,084 kg	1.5 million pesos sunken; 3 million pesos captured

Notes: The loss figures listed in the table account for the loss of unregistered silver (see text). [1]Loss calculated as American production destined for Spain from TePaske (2010), minus 10% American retention rate, minus the Spanish arrival figure provided in the source. [2]Also lists other disaster events which are not included here, because they did not result in the loss of money; e.g. because the disaster occurred on outbound voyages or because an accessible wreck site allowed for rapid salvaging. [3]URL: `http://www.historyofparliamentonline.org/volume/1715-1754/member/wager-sir-charles-1666-1743#footnoteref3_g4iwhgx`. [4]Loss associated with the ship "El Salvador" corrected to 240,000 pesos; correction confirmed with the author.

A.2. Price and wage indices

Table A.2: Price indices

Index	Input variables	Coverage	Source
		Foodstuffs	
Grains & Vegetables	barley, wheat, rice, legumes	1531–1800; Madrid, Seville, Valladolid, Barcelona, Valencia	Losa and Zarauz (2021)
Animal products	mutton, beef, eggs, fish, honey	—"—	—"—
Cheese & Wine	wine, cheese	—"—	—"—
		Heating	
Firewood	firewood	—"—	—"—
Charcoal	charcoal	—"—	—"—
		Consumer & intermediate goods	
Soap	soap	—"—	—"—
Olive oil	olive oil	—"—	—"—
Candles	candles	—"—	—"—
		Textile industry: inputs & intermediate	
Wool (unwashed)	unwashed wool	1558–1808 (with gaps); Casla church, Guadalupe monestary, Segovia Cathedral, Andalusia/Seville, Old Castile	Phillips and Phillips (1997); Drelichman (2009)
Threads	twine, black thread, white thread, yarn	1651–1800; New Castile	Hamilton (1947)
		Textile industry	
Fine cloths	white cloth, serge, linen	—"—	—"—
Coarse cloths	burlap, sackcloth, grogram	1651–1800 (with gaps); New Castile	—"—
		Metals industry	
Iron	iron	1655–1779; Basque region	Arregui (1991)
Iron nails	iron nails	1533–1605 (with gaps); Old Castile-León, New Castile	Global prices and incomes database; compiled from Hamilton (1934, 1936, 1947)

Table A.3: Wage indices

Index	Input variables	Coverage	Source
		Primary sector	
Shepherds	shepherds	1545–1800 (with gaps); Barcelona & surroundings	Feliu (1991)
Unskilled labor	agricultural day laborers, shepherd boys	1546–1809 (with gaps); Andalusia, Catalonia, Old Castile/Palencia	Feliu (1991); Lázaro (2001); Carrión (2002)
		Secondary sector: guild rank	
Masters	carpenters, masons, stonecutters	1531–1798 (with gaps); Andalusia, New Castile, Barcelona, Valencia	Hamilton (1934); Feliu (1991)
Journeymen	carpenters, masons, stonecutter, blacksmiths, cabinetmakers, wheelwrights	1531–1800 (with gaps); Andalusia, New Castile, Valencia	Hamilton (1934, 1947)
Helpers	masons, blacksmiths, cabinetmakers, carpenters	1531–1800 (with gaps); New Castile, Barcelona, Valencia	Hamilton (1934, 1947); Feliu (1991)
		Secondary sector: industries	
Construction workers	unskilled builders	1531–1800; Madrid, Seville, Valladolid, Barcelona, Valencia	Losa and Zarauz (2021)
Weavers	weavers	1531–1650 (with gaps); Valencia	Hamilton (1934)
		Service sector	
Relationship-specific	sacristans, bookkeepers, wardrobe keepers, doormen, stewards	1531–1650; Andalusia, New Castile, Valencia	Hamilton (1934)
Other	nurses, wetnurses, laundress, draymen, basket emptiers, cart loaders, gardeners, cooks, maids	1531–1650; Andalusia, Old Castile-León, Valencia	Hamilton (1934)

A.3. Lending Rates

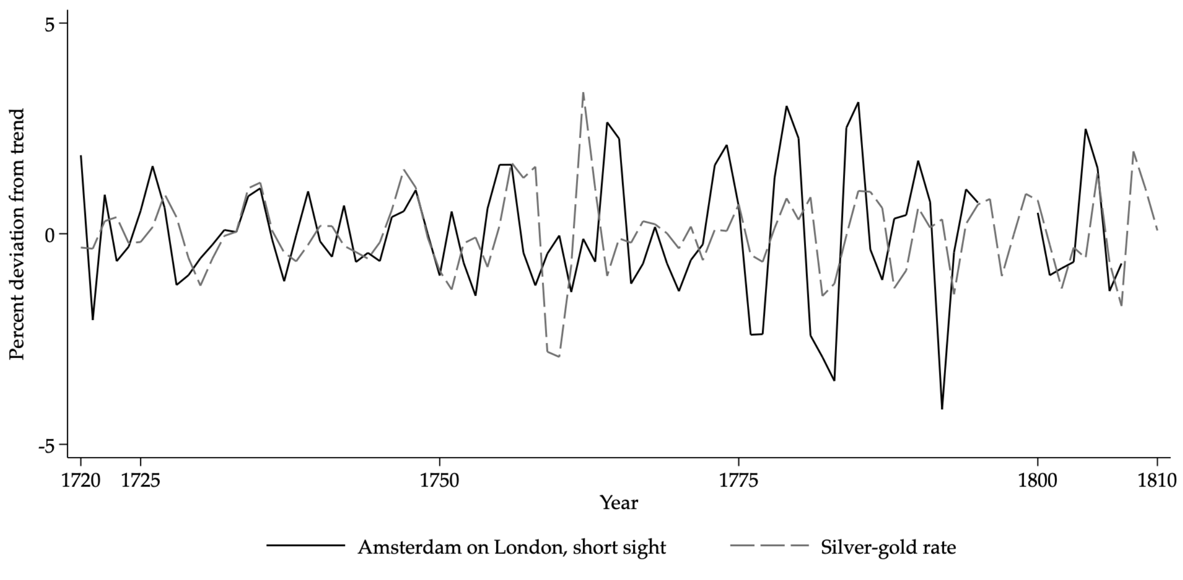
Extensive datasets on early modern bill prices have been compiled by Da Silva (1969), Schneider et al. (1992, 1994), and Denzel (2010). It is possible to estimate (unobserved) lending rates from (observed) bills of exchange prices (Flandreau et al., 2009a; Nogues-Marco, 2011). In this section we describe two methods of doing so.

A.3.1 Accounting for nominal exchange rate fluctuations

Consider the following non-arbitrage condition: Suppose a London merchant possesses Pound Sterling (£), but wants to obtain 1 Spanish Peso (P) in Seville in one month's time. The merchant can do this in two ways. First, he can buy a bill of exchange on Seville with one month maturity for U_t^L Pounds in London. This bill of exchange entitles the merchant to receive 1 Spanish Peso in Seville in one month. Alternatively, the merchant can purchase Pesos on the spot exchange market at the spot exchange rate $E_t^{P/\pounds}$ (Pesos per Pound Sterling). The merchant can then lend out the obtained Pesos in Seville and after one month reclaim the principal times the Sevillian monthly gross lending rate R_t^S. Thus, to receive 1 Peso in one months time, the second approach requires the merchant to initially buy $1/R_t^S$ Pesos for $1/[E_t^{P/\pounds} R_t^S]$ Pounds.

This example clarifies how the price of a bill of exchange can be interpreted as con-

Figure A.5: Exchange rate vs. gold-silver rate



Notes: Exchange rate data based on Amsterdam price of short sight bill on London. Cyclical fluctuations based on HP detrended series ($\lambda = 6.25$).

taining a spot exchange rate component and a lending rate component:

$$U_t^L = 1/[E_t^{P/£} R_t^S]. \tag{A.1}$$

Taking logs and detrending we obtain

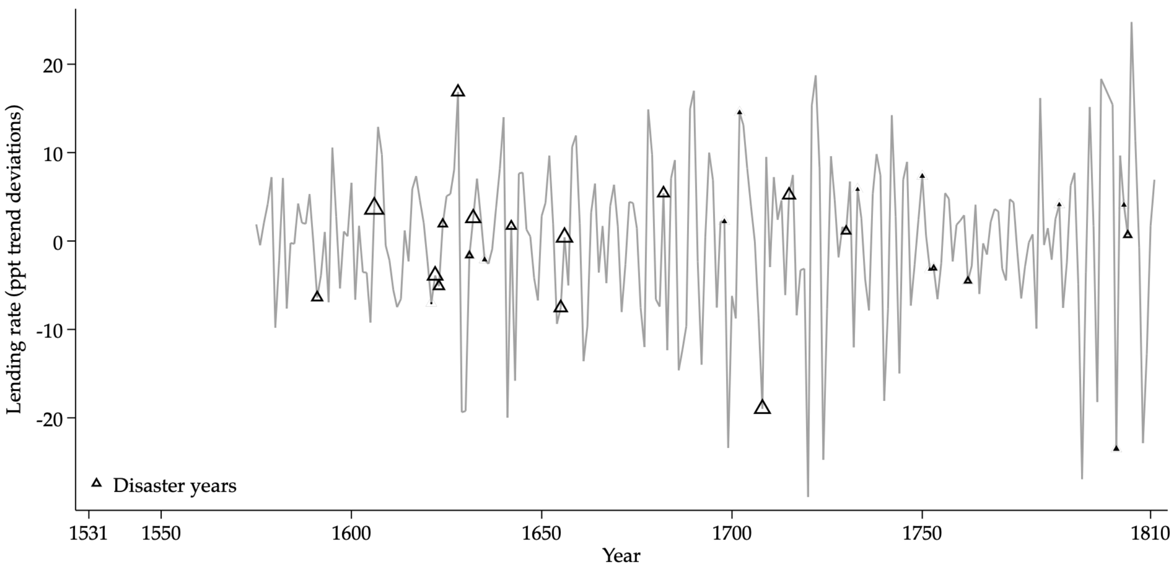
$$\hat{r}_t^S = -\hat{u}_t^L - \hat{e}_t^{P/£}, \tag{A.2}$$

where small letters denote logs, and detrended variables are denoted with hats. Bill of exchange prices inform us about $\hat{u}_t^L$. To obtain an estimate for fluctuations in the Sevillian loan rate, $\hat{r}_t^S$, we need information about spot exchange rate fluctuations, $\hat{e}_t^{P/£}$.

In our sample, currencies were commodity based. Spot exchange rates thus depended on the relative price of different monetary metals – typically gold or silver. This can be seen by comparing fluctuations in silver-gold rates with fluctuations in the price of short sight bills. Short sight bills were redeemable immediately upon presentation to the payer; their price thus resembles a spot exchange rate. Figure A.5 compares fluctuations in the silver-gold rate with fluctuations in the Amsterdam price for a short sight bill on London. Although fluctuations in the silver-gold rate are not perfectly described by fluctuations in the Amsterdam bill price, the two series are highly correlated.

Absent short sight bill prices for Spanish cities, we therefore use silver-gold rates as an indicator for spot exchange rates to calculate Spanish lending rates according to equation A.2. For two silver-based currencies, e.g. Dutch Guilders and Spanish Pesos, this assumes that bill of exchange price fluctuations represent lending rate fluctuations. By contrast,

Figure A.6: Lending rate



for a gold-based currency, e.g. Pound Sterling after 1717, we subtract silver-gold rate fluctuations from bill of exchange price fluctuations to arrive at Spanish lending rates.

We use equation A.2 to calculate fluctuations in the lending rates for seven Spanish cities: Barcelona, Cadiz, Madrid, Medina del Campo, Saragossa, Sevilla, Valencia. We then calculate aggregate Spanish lending rate fluctuations as the average across these seven cities. Figure A.6 depicts the resulting series. The series' standard deviation is 8.8 ppts. For comparison, the standard deviations for analogously detrended long-run returns data for advanced economies in modern times are as follows: 18.3 ppts for the total returns on equity shares, 7.1 ppts for total housing returns, and 6.9 ppts for long-term government bonds (based on data from Jordà et al., 2019, for 17 developed economies from 1870 to 2016).

A.3.2 Transportation times and transaction costs

The non-arbitrage condition described above abstracts from transportation times and transaction costs. International arbitrage in the early modern period, however, required the international transport of letters and money. Travelling from London to Seville by boat took about two weeks. Travelling from Genoa to Seville took somewhat less. Incorporating such frictions into a more realistic non-arbitrage condition gives rise to a non-arbitrage band that implies an upper and lower bound lending rate estimate.

15 days constituted a smooth transit from Seville to London, based on an a distance of 1300 nautical miles and an average shipping speed of 4 knots – the typical speed of Spanish mail boats (Kelly and Ó Gráda, 2019). The respective journey time from Genoa to Seville is 11 days for 1100 nautical miles. In the following analysis of transportation times and their implication for lending rate estimates we therefore consider trips of two weeks.[7]

Consider a bill of exchange issued in London at time t that delivers 1 Peso in Seville at time $t+1$. Let the price of this bill of exchange be $U^L_{t,t+1}$ Pounds. First, to derive the upper bound lending rate estimate, consider the following arbitrage strategy:

1. Sell the bill of exchange in London at time t and exchange the obtained amount ($U^L_{t,t+1}$ Pounds) into Pesos at the spot exchange rate $E_t^{P/£}$ (Pesos per Pound Sterling).
2. Travel to Seville with the Peso receipt from step 1 ($U^L_{t,t+1}E_t^{P/£}$), and lend the Pesos out at the Sevillian interest rate for a period lasting from $t+\tilde{t}$ to $t+1$, where $\tilde{t}$ denotes the travel time between London and Seville. We denote the associated Sevillian

[7] Overland transportation times were similar. With an average speed of 100 miles per day letters could travel faster than anything else in early modern Europe (Parker, 2014, p.299).

gross interest rate by $R^S_{t+\tilde{t},t+1}$. We also allow the transportation and exchange of money to be associated with a proportional transportation and transaction cost $\tilde{\theta}$. Thus, the remaining Peso amount that can be lent out in Seville after transport and transaction costs is $U^L_{t,t+1}E^{P/£}_t(1-\tilde{\theta})$.

3. At $t+1$ in Seville, the bill of exchange and the loan mature, implying an expenditure of 1 Peso and a receipt of $U^L_{t,t+1}E^{P/£}_t(1-\tilde{\theta})R^S_{t+\tilde{t},t+1}$ Pesos.

The bill of exchange is too expensive, i.e. $U^L_{t,t+1}$ is too high, if $U^L_{t,t+1}E^{P/£}_t(1-\tilde{\theta})\mathbb{E}_t R^S_{t+\tilde{t},t+1} > 1$. In this case, the above strategy implies an expected profit. Arbitrage activity thus works towards establishing the following inequality:

$$\begin{aligned} U^L_{t,t+1}E^{P/£}_t(1-\tilde{\theta})\mathbb{E}_t R^S_{t+\tilde{t},t+1} &\leq 1 \\ \Leftrightarrow \mathbb{E}_t R^S_{t+\tilde{t},t+1} &\leq \frac{1}{U^L_{t,t+1}E^{P/£}_t(1-\tilde{\theta})} \end{aligned}$$

With $\Omega^U_t \equiv \frac{\mathbb{E}_t R^S_{t+\tilde{t},t+1}}{R^S_{t,t+1-\tilde{t}}}$, we can write the above inequality as

$$R^S_{t,t+1-\tilde{t}} \leq \frac{1}{U^L_{t,t+1}E^{P/£}_t(1-\tilde{\theta})\Omega^U_t}.$$

After taking natural logarithms, detrending, and periodizing the lending rate, fluctuations in the upper bound lending rate, $\hat{r}^U_t$, are defined as:

$$\hat{r}^S_{t,t+1} \leq \frac{1}{1-\tilde{t}}\left(-\hat{u}^L_{t,t+1} - \hat{e}^{P/£}_t - \hat{\omega}^U_t\right) \equiv \hat{r}^U_t, \tag{A.3}$$

where small letters denote logs, and detrended variables are indicated with hats. The periodization term $1/(1-\tilde{t})$ is necessary to translate a lending rate that pertains to the sub-period $t, t+1-\tilde{t}$ to a lending rate that covers one whole period, $t, t+1$. Besides the periodization term, the only other term that this equation adds to the non-arbitrage condition without transportation time is ω^U_t – log-detrended Ω^U_t. Ω^U_t can be decomposed into two economically meaningful terms: $\Omega^U_t = \frac{\mathbb{E}_t R^S_{t+\tilde{t},t+1}}{R^S_{t,t+1-\tilde{t}}} = \frac{\mathbb{E}_t R^S_{t+\tilde{t},t+1}}{R^S_{t+\tilde{t},t+1}} \frac{R^S_{t+\tilde{t},t+1}}{R^S_{t,t+1-\tilde{t}}}$. The two terms reflect an expectation error and a travel lag, both of which are inherent in non-instantaneous arbitrage activity. The expectation error stems from merchants forming an expectation at time t about $t+\tilde{t}$ lending rates in Seville. The travel lag term describes how the Sevillian lending rate changes during the journey from London to Seville, i.e. the period during which the arbitrage activity has commenced through the sale of a bill in London, but during which the lending rate for the Sevillian loan has not yet been locked in. These expectation error and travel lag terms reflect the two ways in which London bill prices and spot exchange rates become informationally insufficient as a description of Sevillian lending rates in a non-zero travel time environment.

Unfortunately, Ω_t^U is not observable. However, it is possible to assess how the omission of this term in the calculation of the upper bound lending rate series $\hat{r}_t^U$ affects our IRF estimate for this variable. First, consider the expectation error term. In our setting, the expectation error pertains to a two week window after the money shock hits Seville, and during which news about the disaster has not yet arrived in London. The informational insufficiency of London bill prices with respect to Sevillian credit market conditions thus only pertains to one out of 12 monthly bill price observations, whose average forms the annual bill price which enters the lending rate series calculation. This annual averaging dilutes the influence of this one monthly bill price. For example, when lending rates in Seville unexpectedly increase by 2 ppts, from 7 to 9%, in response to a maritime disaster in t, and merchants in London continue to expect a 7% Sevillian lending rate until the bad news arrives, then the annual expectation error term will be $0.9984 = (1.07^{1/12} \cdot 1.09^{11/12})/1.09$. Omitting this term implies an underestimate of the actual upper bound lending rate increase in disaster years of around 0.16 ppts ($= 1/0.9984 - 1$). An IRF estimate based on the upper bound lending rate series that neglects the expectation error would thus modestly underestimate the actual on-impact response of the upper bound, thus somewhat narrowing the upper-lower bound IRF range. However, to the extent that credit rationing initially led to a reduction in the quantity of credit supplied, rather than an increase in lending rates, the topic is moot. This is because no systematic expectation error with respect to Sevillian lending rates emerges.

Second, consider how the omission of the travel lag term $\frac{R^S_{t+\tilde{t},t+1}}{R^S_{t,t+1-\tilde{t}}}$ affects the upper bound lending rate IRF estimate. In our setting, when a money shock hits at t the travel lag term turns less than 1 to the extent that the Sevillian lending rate immediately after the shock $t, t+1-\tilde{t}$ exceeds the lending rate two weeks further down the road. Omitting this term in the calculation of the upper bound lending rate thus leads us to underestimate the on-impact increase in the upper bound lending rate series during maritime disaster years. The informational deficiency of London bills and spot exchange rates that the travel lag term compensates for is again restricted to a two week period and thus a single monthly bill price observations. Assuming Seville's lending rate increases by 2 ppts in t, from 7 to 9%, and then falls back to 7% after $t+1-\tilde{t}$, then the annual travel lag term again amounts to 0.9984. As for the expectation error term, credit rationing renders the issue moot, to the extent that the Sevillian lending rate does not systematically change between t and $t+1$.[8]

Next, we derive a lower bound lending rate estimate. If the London-issued bill of exchange on Seville is too cheap, the following strategy is profitable:

[8]Beyond the behavior of $\hat{\omega}_t^U$ in response to money shocks, there exist other shocks that will push $\hat{\omega}_t^U$ up and down. More generally, omitting this term in the calculation of the upper bound lending rate thus introduces a measurement error, which likely increases the standard error of any IRF estimate.

1. At time $t-\tilde{t}$, borrow $\mathbb{E}_{t-\tilde{t}}\left[U^L_{t,t+1}E^{P/£}_t\right]/(1-\tilde{\theta})$ Pesos in Seville for the period $t-\tilde{t}$ to $t+1$ at the local interest rate $R^S_{t-\tilde{t},t+1}$.
2. Travel to London, deduct transportation and transaction costs from the amount borrowed in step one[9], and exchange the remainder, $\mathbb{E}_{t-\tilde{t}}\left[U^L_{t,t+1}E^{P/£}_t\right]$, into Pounds at the spot exchange rate $E^{P/£}_t$. Use the obtained Pounds to buy bills of exchange on Seville at the price $U^L_{t,t+1}$. The total number of bills of exchange that can be bought in this way is $\mathbb{E}_{t-\tilde{t}}\left[U^L_{t,t+1}E^{P/£}_t\right]/(U^L_{t,t+1}E^{P/£}_t)$.
3. Travel back to Seville with the bills of exchange. At time $t+1$, both the bill of exchange and the loan mature, leading to the receipt of $\mathbb{E}_{t-\tilde{t}}\left[U^L_{t,t+1}E^{P/£}_t\right]/(U^L_{t,t+1}E^{P/£}_t)$ Pesos and an expenditure of $\mathbb{E}_{t-\tilde{t}}\left[U^L_{t,t+1}E^{P/£}_t\right]/(1-\tilde{\theta})R^S_{t-\tilde{t},t+1}$ Pesos.

The bill of exchange is too cheap if $1/(U^L_{t,t+1}E^{P/£}_t) > 1/(1-\tilde{\theta})R^S_{t-\tilde{t},t+1}$. Arbitrage leads to

$$R^S_{t-\tilde{t},t+1} \geq \frac{1-\tilde{\theta}}{U^L_{t,t+1}E^{P/£}_t}$$

Define $\Omega^L_t = \frac{R^S_{t,t+1+\tilde{t}}}{R^S_{t-\tilde{t},t+1}}$, and periodize the interest rate to get

$$R^S_{t,t+1} \geq \left(\frac{(1-\tilde{\theta})\Omega^L_t}{U^L_{t,t+1}E^{P/£}_t}\right)^{1/(1+\tilde{t})}$$

After taking natural logarithms and detrending we arrive at the lower bound lending rate estimate

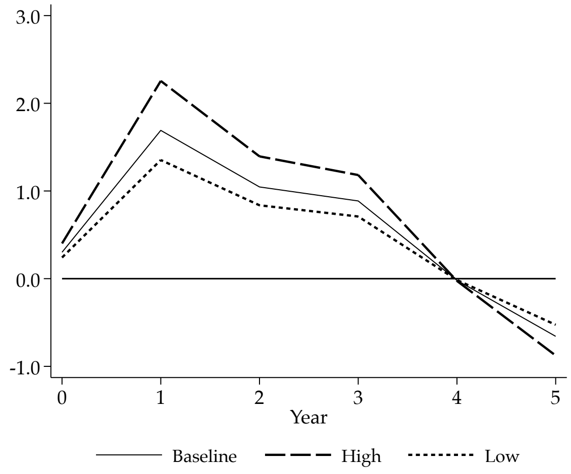
$$\hat{r}^S_{t,t+1} \geq \frac{1}{1+\tilde{t}}\left(-\hat{u}^L_{t,t+1} - \hat{e}^{P/£}_t + \hat{\omega}^L_t,\right) \equiv \hat{r}^L_t,$$

where small letters denote logarithms, and hats indicate detrended variables. Besides the periodization term $1/(1+\tilde{t})$ the lower bound lending rate thus includes a travel lag term – log-detrended $\Omega^L_t = \frac{R^S_{t,t+1+\tilde{t}}}{R^S_{t-\tilde{t},t+1}}$. This term is unobservable, and we thus calculate the lower bound lending rate series as $\frac{1}{1+\tilde{t}}\left(-\hat{u}^L_{t,t+1} - \hat{e}^{P/£}_t\right)$. This affects the lower bound lending rate series in a similar way as the omission of Ω^U_t affects the upper bound series. Again, the travel lag term compensates for the informational deficiency of London bill prices and spot exchange rates with respect to contemporaneous Sevillian lending rates.

In our setting, when a money shock hits at t the travel lag term turns above 1 to the extent that the Sevillian lending rate increases in response to the shock. Omitting this term in the calculation of the lower bound lending rate thus leads us to underestimate

[9] This should include an amount set aside for the return journey to Seville.

Figure A.7: Lending rate IRF range implied by a two-week travel time



Notes: Solid line – baseline response. Upper and lower bound IRFs for a two-week travel time period.

the on-impact increase in the lower bound lending rate series during maritime disaster years. The informational deficiency of London bill prices and spot exchange rates is again restricted to a two week period and thus a single monthly bill price observations. Assuming Seville's lending rate increases by 2 ppts in t, from 7 to 9%, and remains at 9% thereafter, then the annual travel lag term amounts to $1.0015 = 1.09/(1.07^{1/12} \cdot 1.09^{11/12})$, implying a 0.15 ppt underestimation of the actual lower bound lending rate resulting from omitting the travel lag term. As for the expectation error term, credit rationing renders the issue moot, to the extent that the Sevillian lending rate has no on-impact response to the money shock.

Assuming a transportation time of two weeks and a bill of exchange maturity of two months, the scaling factors $\frac{1}{1+\tilde{t}}$ and $\frac{1}{1-\tilde{t}}$ amount to 0.8 and 1.33 respectively. Figure A.7 shows the upper and lower bound rate responses we obtain for the two-week travel time scenario. The upper bound rate response suggests that lending rates increased around 2 percentage points in response to a negative 1 ppt money growth shock. According to the lower bound rate response lending rates increased by around 1.2 percentage points. The omission of expectation error and travel lag terms in the calculation of the upper and lower bound lending rate series implies that the on-impact IRFs are potentially afflicted by a downward bias. However, no bias is present to the extent that Spain's on-impact response to maritime disasters was characterized by credit rationing instead of an increase in lending rates. In sum, while transportation times add to the uncertainty in the lending rate response the evidence suggests that lending rates increased between one and two ppts after a 1 ppt money inflow shock.

A.3.3 Cancelling nominal exchange rate fluctuations

Gold-silver rate fluctuations can be an inaccurate proxy for nominal exchange rate fluctuations. This is because transportation costs can impede the arbitrage that would align nominal exchange rates with (bi-)metallic exchange rates (Bernholz and Kugler, 2011; Nogues-Marco, 2013). This opens the door for deviations between nominal exchange rates and (bi-)metallic exchange rates. For example, in the aftermath of a maritime disaster an acute shortage of Spanish silver coins may lead to an appreciation of Spanish peso coins in spot exchange markets that is not reflected in the gold-silver rate. Relatedly, falling prices for tradable goods in Spain may contribute to upward pressure on the Spanish exchange rate as merchants bid up the price of bills of exchange that provide them with the Spanish currency they require to buy the cheaper Spanish tradable goods.[10] Another concern is that merchants may have deemed Spanish coin debasements more likely after maritime disasters. As a consequence, post-disaster bill price changes might reflect debasement fears rather than Spanish lending rate fluctuations. This section describes an approach to calculating lending rates from bill prices that is robust to such concerns.

The currency market exchange rate of Spanish coins can be taken entirely out of the picture by using the prices of bills of exchange of different maturity. Consider an Amsterdam bill of exchange on Seville with 1-month maturity and a London bill of exchange on Seville (or another Spanish city) with 2-month maturity. The price for the Amsterdam bill is

$$U_t^{A,1m} = 1/[E_t^{P/G} R_t^{S,1m}], \tag{A.4}$$

where $E_t^{P/G}$ is the spot exchange rate between Dutch Guilders and Spanish Pesos (Pesos per Guilder), and $R_t^{S,1m}$ is the one-month lending rate in Seville. Analogously, the price for the London bill of exchange is

$$U_t^{L,2m} = 1/[E_t^{P/£} R_t^{S,2m}], \tag{A.5}$$

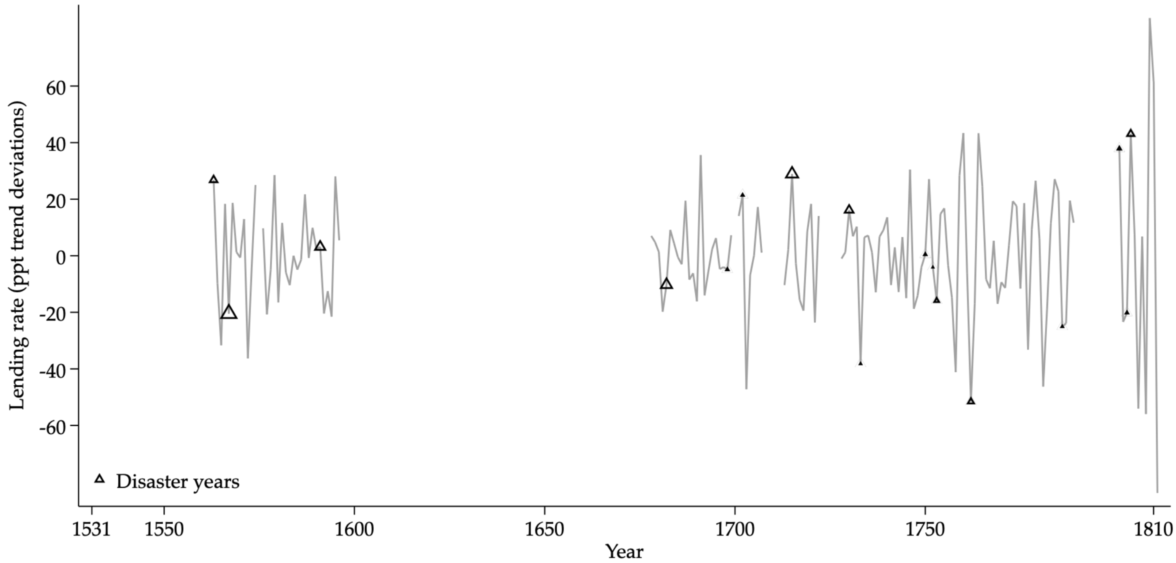
where $R_t^{S,2m}$ is the two-month lending rate in Seville. Dividing the two prices, we arrive at

$$\frac{U_t^{A,1m}}{U_t^{L,2m}} = \frac{E_t^{P/£}}{E_t^{P/G}} \frac{R_t^{S,2m}}{R_t^{S,1m}} = E_t^{G/£} R_t^{S,1m}. \tag{A.6}$$

$E_t^{G/£}$ is the spot exchange rate between Pounds Sterling and Dutch Guilders (Guilders per Pound). In other words, fluctuations of the nominal exchange rate of Spanish currency are cancelled out of expression A.6. What remains is the nominal exchange rate between two non-Spanish currencies that is unlikely to be affected by a scarcity or Spanish currency

[10] Both these scenarios would imply that our baseline approach to calculating lending rates from bill prices would disguise some of the actual lending rate increase in the aftermath of maritime disasters.

Figure A.8: Lending rate, NER cancelation approach



or Spanish debasement risk in the aftermath of maritime disasters. The log-detrended relative price of two bills of exchange of different maturity thus can serve as a proxy of the variation in the Spanish monthly interest rate. The main drawback of this alternative approach is the scarcity of suitable bill of exchange pairs of different maturity. As a consequence, this approach produces one third fewer observations than the (bi-)metallic ratio-based approach.

Figure A.8 shows the lending rate series that results from canceling the Spanish currency's exchange rate in this way (*NER cancelation rate*). With a standard deviation of 22, it exhibits more variation than the lending rate based on using the gold-silver rate as an indicator for the spot exchange rate (*NER proxy rate*). Partly this is due to the extremely high volatility of the NER cancelation rate at the end of the sample during the Napoleonic Wars, the exclusion of which lowers the series' standard deviation by 4.5 ppts to 17.5. The prime suspect behind the NER cancelation series' higher volatility, however, is that in contrast to the NER proxy series it is not an average of lending rates across various Spanish cities. Instead, at each point in time, it reflects price fluctuations of bills of exchange on only one or two Spanish cities. As a consequence, the NER cancelation series lacks the variance reducing effect of the diversification implicit in summing across less than perfectly correlated Spanish market places. This is confirmed by the data: Three of the lending rates series for the individual Spanish cities that underlie the NER proxy rate have standard deviations above 19 ppts. One upshot of this is that the NER cancelation series is less representative of lending rate fluctuations in Spain as a whole, and hence we prefer the NER proxy lending rate series.

Figure A.9: Alternative lending rate responses (negative 1 ppt money inflow shock)

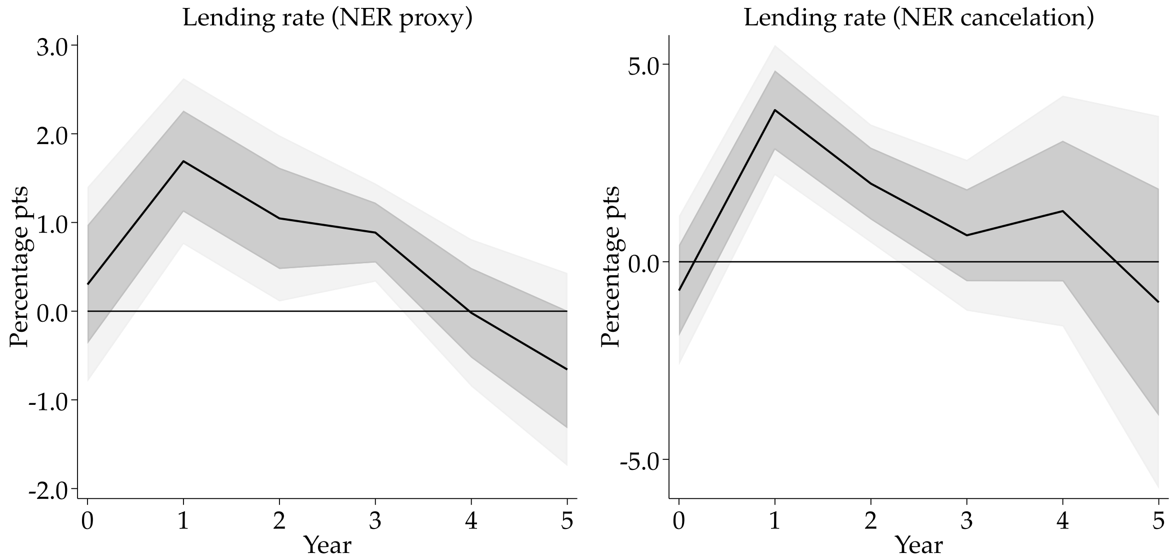


Figure A.9 compares the IRFs of both lending rate measures. According to both measures lending rates increased significantly one year after the shock. The NER cancelation rate's peak response, however, is about 2.5 times as large as the NER proxy rate's response. It is also somewhat less persistent.

A.3.4 Data on bill of exchange prices

Europe's early modern financial centers quoted bills of exchange prices for several Spanish market places. Our sources for the bills of exchange prices are Da Silva (1969), Schneider et al. (1992, 1994), and Denzel (2010). In our data collection we focus on quotations from the largest financial centers (Amsterdam, London, Paris), as well as several other important nodes in the European financial network (Antwerp, Bisenzone fairs, Genoa, Hamburg, Venice) (Flandreau et al., 2009b). Since the bill of exchange price data for specific financial hub-destination pairs are often limited in length, we combine price quotations from different financial hubs to construct long-run time series (Table A.4). Based on these, we use equation A.2 to calculate fluctuations in the average Spanish lending rate as $\hat{r}_t^{Spain} = \frac{1}{I}\sum_i \hat{r}_t^i$, where $i \in$ {Barcelona, Cadiz, Madrid, Medina del Campo, Saragossa, Sevilla, Valencia}.[11]

The maturity of a typical bill of exchange ranges between 1 and 3 months. We use bills

[11]Bisenzone was the Genoese exchange fair. As the Genoese used the Bisenzone fair to raise money for the Spanish Crown, one concern is that the bill prices at the Bisenzone fair reflect the financial standing of the Spanish Crown, rather than the Spanish private sector (Pezzolo and Tattara, 2008). However, the NER cancelation rate response (Figure A.9) which is not based on bill prices from the Bisenzone fair, suggests that the positive lending rate response is not driven by the behavior of bill prices on this fair.

Table A.4: Bills of exchange, NER proxy

Time period	Destination city	Financial center
1590 - 1796	Amsterdam	London
1575 - 1685		Bisenzone
1686 - 1697	Antwerp	London, Bisenzone
1756 - 1764		London, Venice
1678 - 1699	Cadiz	Amsterdam (1700: Antwerp)
1598 - 1722	Barcelona	Bisenzone
1591 – 1722		Bisenzone
1776 – 1785	Frankfurt	Leghorn
1805 – 1811		Paris
1552 - 1674		Bisenzone
1678 - 1698	Genoa	Amsterdam
1699 - 1811		London
1626 - 1666	Hamburg	Venice
1667 - 1811		London
1593 - 1654		Amsterdam
1657 - 1686	London	Amsterdam, Hamburg
1687 - 1806		Hamburg
1580 - 1607		Bisenzone
1661 - 1734	Madrid	Amsterdam
1735 - 1811		London
1579 - 1722	Medina del Campo	Bisenzone
1575 - 1722	Milan	Bisenzone
1740 - 1796		Venice
1619 - 1714	Paris	Amsterdam
1715 - 1811		Hamburg
1598 - 1722	Saragossa	Bisenzone
1575 - 1681		Bisenzone
1682 - 1712	Seville	Amsterdam, Bisenzone
1713 - 1804		Amsterdam
1585 - 1660		Bisenzone
1661 - 1696	Venice	Amsterdam
1698 - 1807		London

of M months maturity to calculate annual interest rates as follows: $\hat{r}_t^{annual} = \frac{12}{M}\hat{r}_t^{Mmonths} = -\frac{12}{M}\hat{u}_t^{Mmonths} - \frac{12}{M}\hat{e}_t^{P/£}$. We obtain detrended logarithms of the prices of bills of exchange, $\hat{u}_t^{Mmonths}$, by applying the HP filter with the smoothing parameter, λ, set to 6.25. Note that this approach provides us with estimates of trend deviations in loan rates, not estimates of loan rate levels. This is an important difference to the approaches pioneered in Flandreau et al. (2009a) and Nogues-Marco (2011), which result in loan rate level estimates.

For the alternative method to derive Spanish interest rates, pairs of bills of exchange with different maturities are required. When data of such pairs are not available for the same Spanish city, we use bills of exchange on different Spanish cities (Table A.5). The Spanish interest rate is then calculated according to equation A.6, and then log-detrended. The maturity difference between the bills of exchange is always one month. Thus the resulting interest rate is monthly. This monthly rate is then multiplied by 12 to arrive at the annual rate.

Table A.5: Bills of exchange, NER cancelation

Time period	Destination city	Financial center	Maturity (month)
1563 - 1574	Valencia	Lyon	1
	Seville	Antwerp	2
1576 - 1596	Valencia	Lyon	1
	Seville	Lyon	2
1678 - 1699	Cadiz	Amsterdam	1
	Madrid	Amsterdam	2
1700 - 1710	Cadiz	Antwerp	1
	Cadiz	Amsterdam	2
1713 - 1777	Madrid	Amsterdam	2
	Madrid	London	3
1778 - 1810	Madrid	Amsterdam	2
	Cadiz	London	3

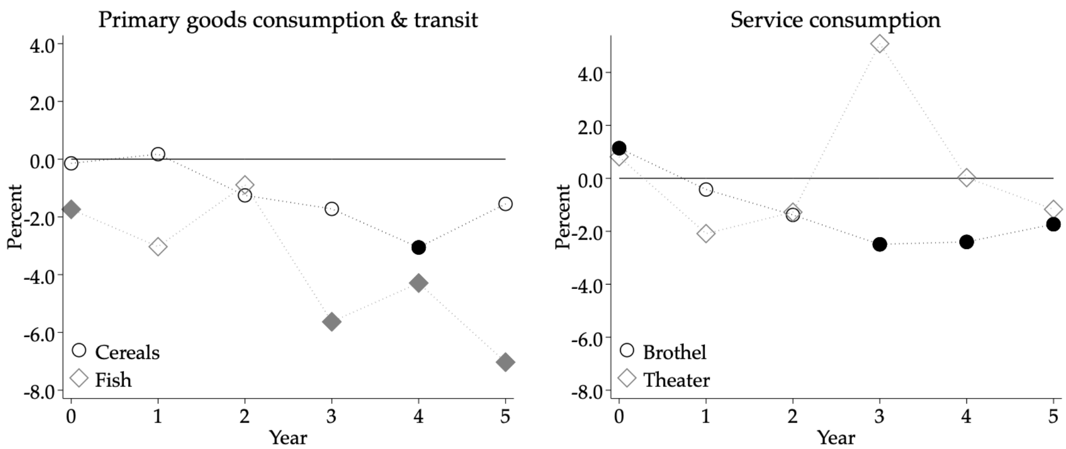
B. Additional results

Table B.1: Silver inflows and Spanish exports

Spanish export (growth rate)	-0.03		-0.03
	(0.02)		(0.03)
L.Spanish export (growth rate)		-0.02	-0.02
		(0.03)	(0.03)
F-statistic (p-value)	0.20	0.52	0.37
R squared	0.10	0.03	0.13
Observations	18	17	17

Notes: * 90%, ** 95%, *** 99%. Standard errors in parentheses. Dependent variable – silver inflow growth rate. Independent variables – Spanish export value growth rate. Export data from Esteban (1981).

Figure B.1: Responses to negative 1 percentage point money inflow shock



Notes: Nominal cereals tax revenues deflated with wheat and barley price index from nearby Madrid (Losa and Zarauz, 2021). Fish tax revenues are deflated with fish prices from Madrid from Allen (2001). The theater and brothel tax revenue series are deflated with the annual wage series for New Castile from Reher and Ballesteros (1993).

Figure B.2: Response to negative 1 percentage point money inflow shock

Notes: Parsimonious specification. Local projections including only two lags of the dependent variable's growth rate, together with leads, lags, and the contemporaneous value of the net money shock variable among the regressors.

B.1. International trade

Price falls in tradable goods, such as iron and wool, raise the question whether Spanish exports increased in the aftermath of contractionary money shocks. Such an increase in exports, when paid for with precious metals, can counteract the monetary contraction at home. Relatedly, a Spanish recession can also lead to a reduction in Spanish import demand, thereby increasing the amount of precious metals that are retained in Spain.[12] The predictions that Spain's monetary loss will thus eventually diffuse across borders is shared by international monetary models, such as the price-specie flow model (Hume, 1752) and the monetary approach to the balance of payments (Flynn, 1978; Frenkel and Johnson, 2013).[13]

Wool and iron were two important export commodities for early modern Spain (Bilbao, 1987; Drelichman, 2009). While trade data for our sample period is generally scarce, available time series on Spanish wool and iron exports are long enough to straddle several maritime disaster events. The iron export data by Bilbao and Fernández de Pinedo (1982) covers exports from Biscayan ports from 1656 to 1805.[14] The wool export data by Alonso (1994) covers exports through Spain's Northern ports from the beginning of our sample until 1585.[15]

The left panel in Figure B.3 describes how Spanish wool and iron exports reacted to the contractionary money shock. Real wool exports initially increased by around 4%.[16]

[12]Relatedly, blanket bans on precious metals exports were in place before 1551, from 1560 to 1566, from 1583 to 1586, from 1590 to 1593, and in 1600 (Martín, 1965, p.xxxii). After 1785, Spanish officials also began to rein in unregistered silver outflows with increasing success (Stein and Stein, 2003, p.310). These dates are not correlated with the occurrence of maritime disasters, and the blanket bans thus did little to increase Spanish money retention in the aftermath of the shocks we analyze.

[13]By modern standards, the early modern Spanish economy was relatively closed. Available export data for the late 18th century, after a period of rapid trade expansion, show that Spain's exports to its colonies averaged 1.5% of Spanish GDP (data from Esteban, 1981; Álvarez-Nogal and Prados de la Escosura, 2013). Lacking export success in other European economies, Spain's colonial exports were an important part of its total exports (Prados de la Escosura and Tortella Casares, 1983; Prados de la Escosura, 1993, pp.276-277). Spain's total export-to-GDP ratio was thus unlikely to exceed 5%. In addition, Spanish money outflows provide an insight into the size of Spain's chronic trade deficit with the rest of Europe. On average, Spanish money outflows amounted to around 94% of its money inflows (Chen et al., 2021). Money inflows, in turn, amounted to 3.7% of Spanish GDP on average. Putting both numbers together suggests that Spanish net-imports amounted to 3.5% of Spanish GDP – a large deficit given the small gross flows.

[14]This export series is calculated from tax auction returns. The tax right entitled the owner to a fixed amount of Maravedis per weight unit of iron exports. The tax auction returns thus reflects real export quantities. As for other tax auction series, an expectation error caveat applies (see section 3.1): To the extent that tax farmers' revenue expectations were disappointed due to the effects of the unexpected monetary shock, the on-impact response calculated from this data fails to reflect the actual response of iron exports.

[15]Wool exports are expressed in "sacks". While the exact content of a "sack" of wool is uncertain, the discussion in the historical literature has settled on a weight estimate of about 80 kilograms (Grafe, 2002; Drelichman, 2009).

[16]Contemporary merchant letters suggest that any wool that could not be sold in Spain was quickly

Within the following two years, Spanish wool exports decline by close to 10%, which ties in with Spain's diminished capacity to produce wool after its flock size has diminished (see section 3.1). Real iron exports from Biscay exhibit no reaction. For the attraction of foreign coins, nominal rather than real exports are crucial. The considerable fall in Spanish iron and wool prices suggests that nominal exports might have fallen considerably (see section 3.2.2). However, we do not observe export prices at Spanish ports, which might have been more stable than Spain's domestic prices.

How did Spanish imports react to the monetary contraction? Spain's iron exports turn out to be informative in this regard. Iron exports were used to pay for non-food imports, because regulation discouraged the use of precious metals for international payment except for the import of foodstuffs (Lonbide and Ruano, 2007). As such, the iron export response can also be interpreted as indicative of Spanish non-food imports arriving at Biscayan ports. Assuming iron's export price fell by no more than iron's domestic price this implies an upper bound for Spain's nominal import reduction through Biscayan ports of 6% within two years (see section 3.2.2).[17]

Another snippet of information on Spain's import response comes from a short time series on exports from Bayonne to Spain between 1746 and 1780 (Jaupart, 1966). Bayonne, a French city that is located just across the French border, was a key node in the Spanish-French overland trade (Stein and Stein, 2003, p.308). Much of the American silver that left Spain through the Basque region and Navarre entered France through Bayonne. The right panel in Figure B.3 displays how Spain's imports from Bayonne behaved in the aftermath of maritime disasters. Imports collapsed by 30% within two years, demonstrating that Spanish import demand was not insulated from monetary contractions.[18] Spanish imports from Bayonne, however, are hardly representative. The close geographic proximity and the high weight of luxury goods among French exports probably rendered imports from Bayonne especially vulnerable to maritime disaster losses and the ensuing belt-tightening among Spanish households (Stein and Stein, 2003, p.313).

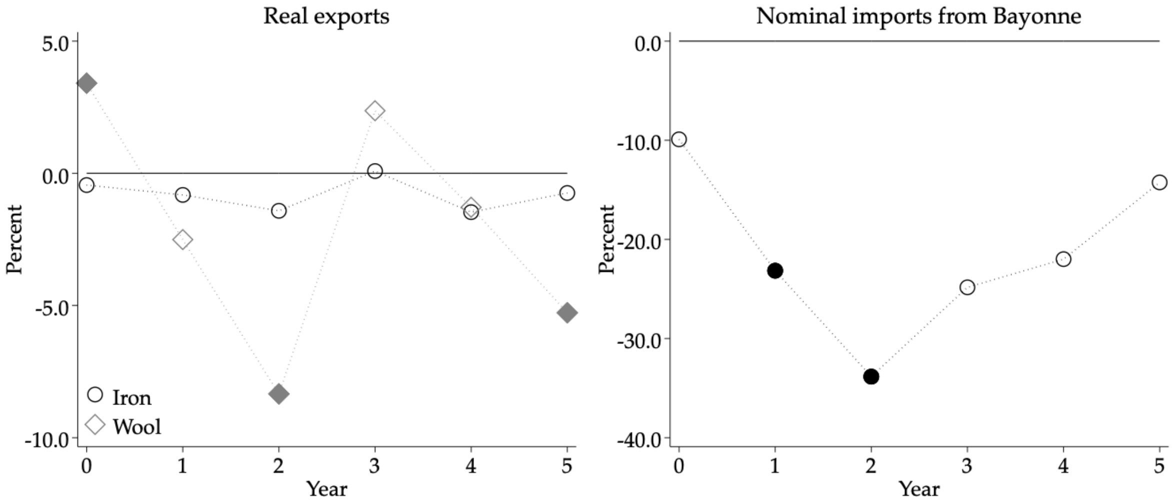
Overall, the wool and iron export IRFs suggest that the diffusion posited by international monetary models did not occur through a short-run increase in exports. Sporadic import evidence, however, is consistent with the notion that Spanish households and merchants curtailed their import demand, and thereby contributed to the diffusion of Spain's

prepared for export (Martín, 1965, p.xc).

[17]The Spanish government took various measures to discourage the outflow of silver money from Spain. As a consequence, wool and iron were frequently used as money substitutes in international trade. To transfer money from Spain to Italy, for example, Genoese merchants bought wool in Spain, exported the wool to Italy, and sold it there. Thus, the decrease in Spanish wool exports may also reflect a reduction in the amounts of funds that merchants desired to transfer from Spain to the rest of Europe.

[18]Note that the four maritime disaster losses that the Bayonne import series straddles are among the smallest, ranging from 0.05% to 1.2% of Spain's money stock (after salvaging).

Figure B.3: International trade response to a -1 percentage point money inflow shock



Notes: Solid markers indicate significance at the 10% level. IRF estimates for imports from Bayonne and wool exports based on parsimonious specification.

money loss to the rest of the Europe.

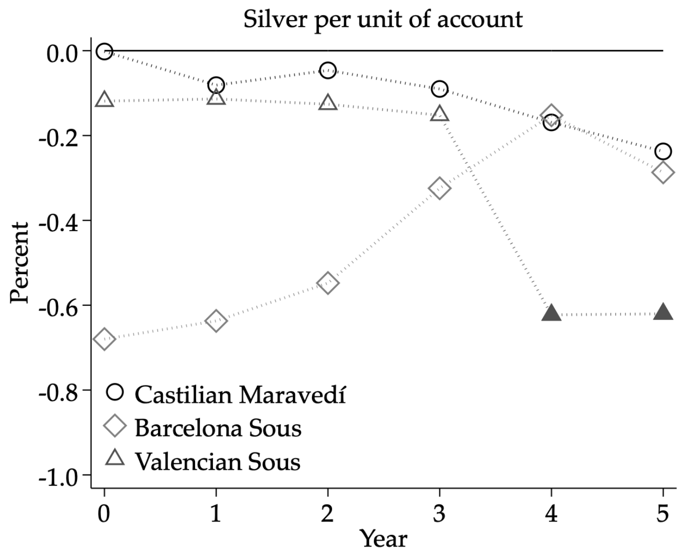
B.2. Changes in the silver value of the unit of account

In early modern Spain nominal adjustments could take place not only through a fall in wages and prices, but also through a change in the silver value of the unit of account (UOA) (Sargent and Velde, 2002; Velde, 2009; Karaman et al., 2018). Wages and prices in Castile were commonly expressed in *Maravedí* – the Castilian UOA – and Castilian coins possessed a *Maravedí* face value. Within the borders of present-day Spain, different UOAs existed. Thus, wages and prices in Barcelona and Valencia were commonly expressed in *Barcelona sous* and *Valencian sous*, respectively. The most direct way in which the silver value of one UOA could change was through the monetary authority's decision to change the silver content of coins. This, however, was an infrequent occurrence. More frequent were fluctuations in the exchange rate between silver coins and copper coins, which within our sample led to fluctuations in silver prices while the same prices expressed in UOAs stayed constant. Here, we analyze whether changes in the silver value of Spanish UOAs contributed to the nominal adjustment of the Spanish economy in the aftermath of maritime disasters.

The silver value of Spanish UOAs was stable for most of the 16th and 18th centuries, but in the 17th century it declined and especially in Castile at times behaved erratically (see Hamilton, 1934, ch. 4 for a detailed description of this period). To see whether such fluctuations in the silver value of Spanish UOAs contributed to nominal adjustments in the Spanish economy we analyze the time series on the silver content of the Castilian *Maravedí*, the *Barcelona sous* and the *Valencian sous* (Allen, 2001; Losa and Zarauz, 2021). We estimate IRFs for these UOAs' silver content based on the baseline specification 1.

Figure B.4 shows the results. For Castile, we find no indication that the silver content of the Maravedí systematically changed in the aftermath of maritime disasters. The silver content of the Barcelona sous falls by 0.6% on impact, but the IRF is statistically insignificant throughout. Only the Valencian sous exhibits a significant debasement, but this only takes place four years after the shock. These IRFs suggest that debasements may have played an auxiliary role for the adjustment of prices and wages denominated in Barcelona sous and Valencian sous. However, the majority of prices and wages analyzed earlier come from Castile, where nominal adjustment cannot be attributed to changes in the UOAs silver content.

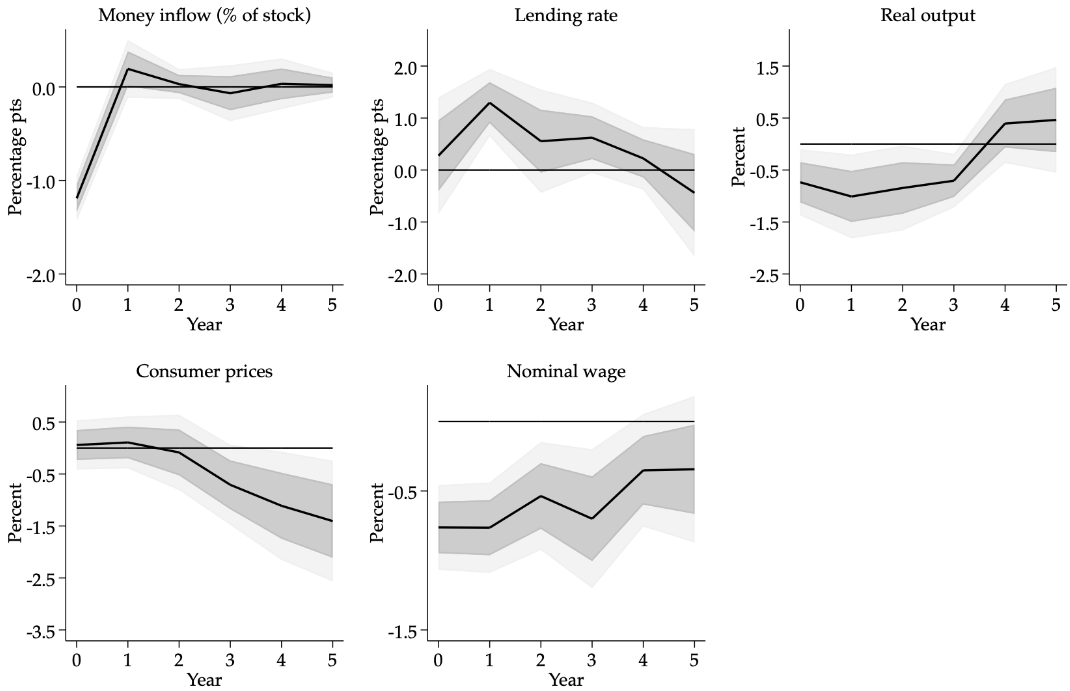
Figure B.4: Currency debasements in response to a -1 percentage point money inflow shock



Notes: Solid markers indicate significance at the 10% level.

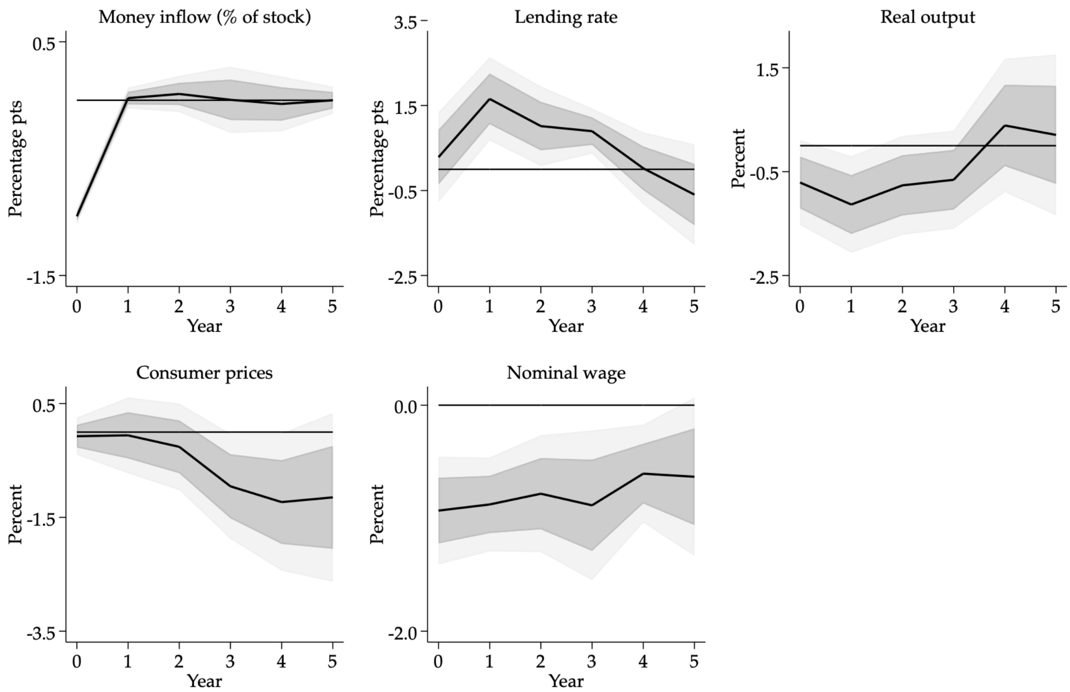
B.3. Robustness checks

Figure B.5: Impulse responses for negative 1 ppt money inflow shock (parsimonious)



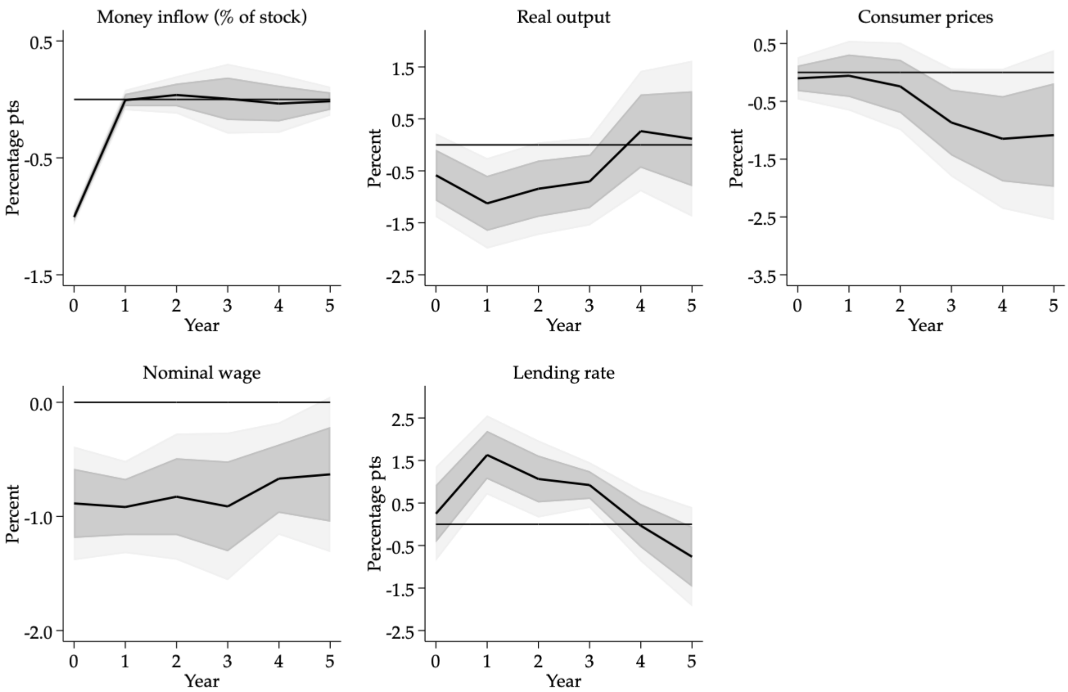
Notes: Parsimonious specification. Local projections including only two lags of the dependent variable's growth rate, and the money shock indicators among the regressors.

Figure B.6: Impulse responses for negative 1 ppt money inflow shock (excl. conflicts)



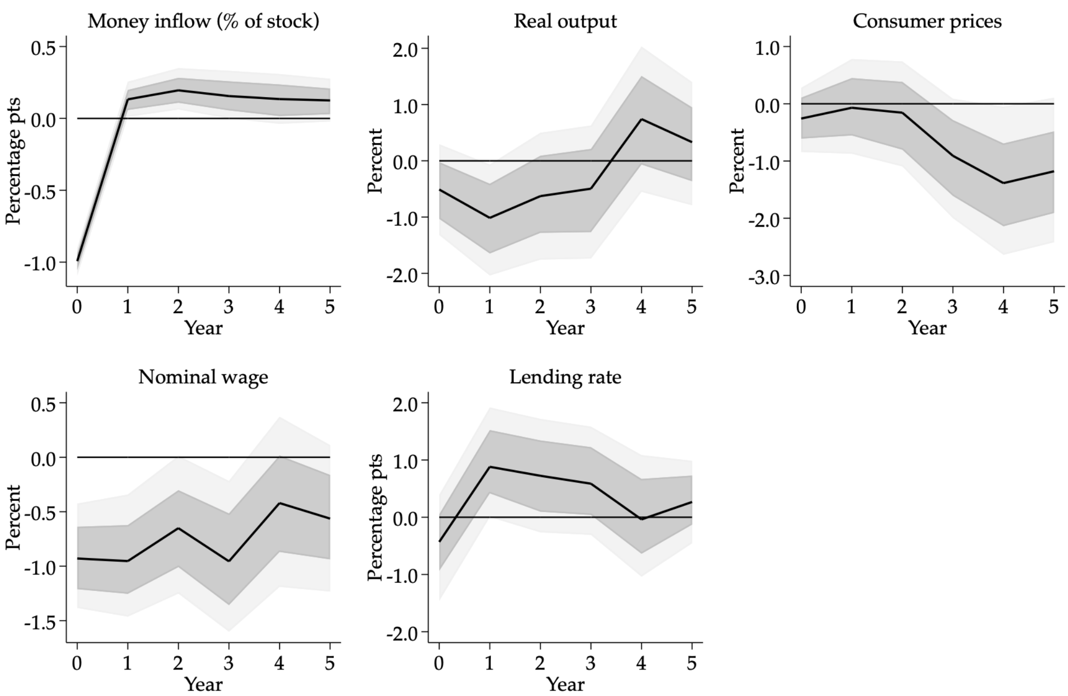
Notes: This figure shows IRF results based on a specification that allows money shocks caused by combat or capture events to develop different effects, by including an interaction term between the money shock and a conflict dummy.

Figure B.7: Impulse responses for negative 1 ppt money inflow shock (excl. salvaged)



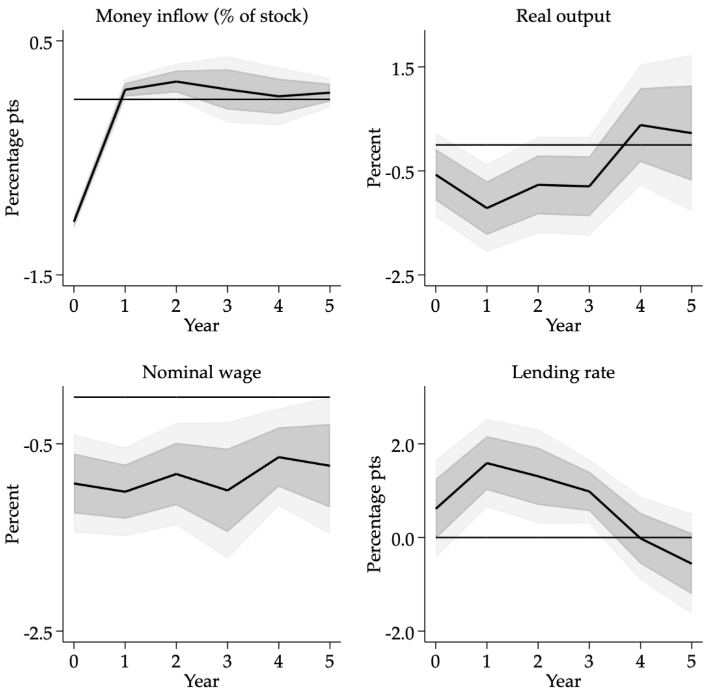
Notes: This figure shows IRF results based on a money shock measure that excludes subsequently salvaged money losses.

Figure B.8: ARDL model results (negative 1 ppt money inflow shock)



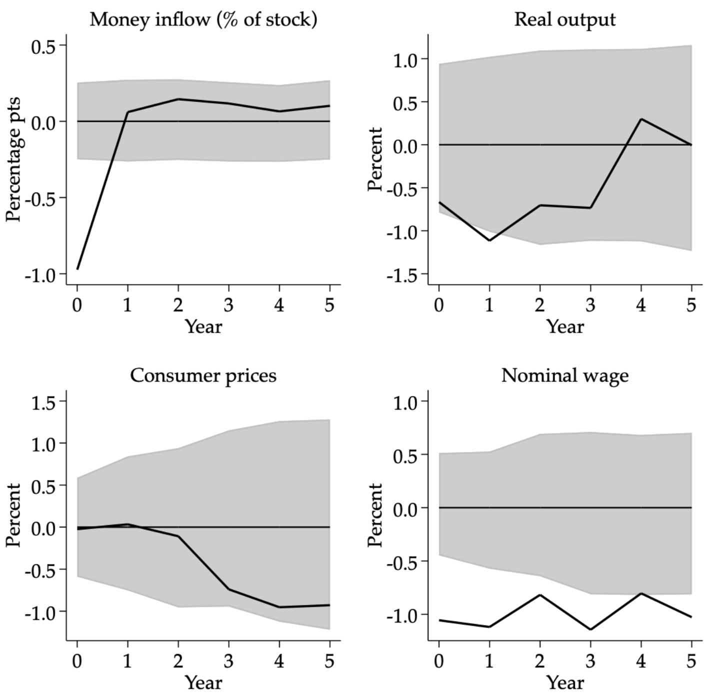
Notes: Autoregressive distributed lag (ARDL) model including up to 4 lags of the endogenous regressors, and up to 4 leads of the exogenous regressors. Money inflows are expresses relative to the current money stock.

Figure B.9: Impulse responses for negative 1 ppt money inflow shock (one month delay)



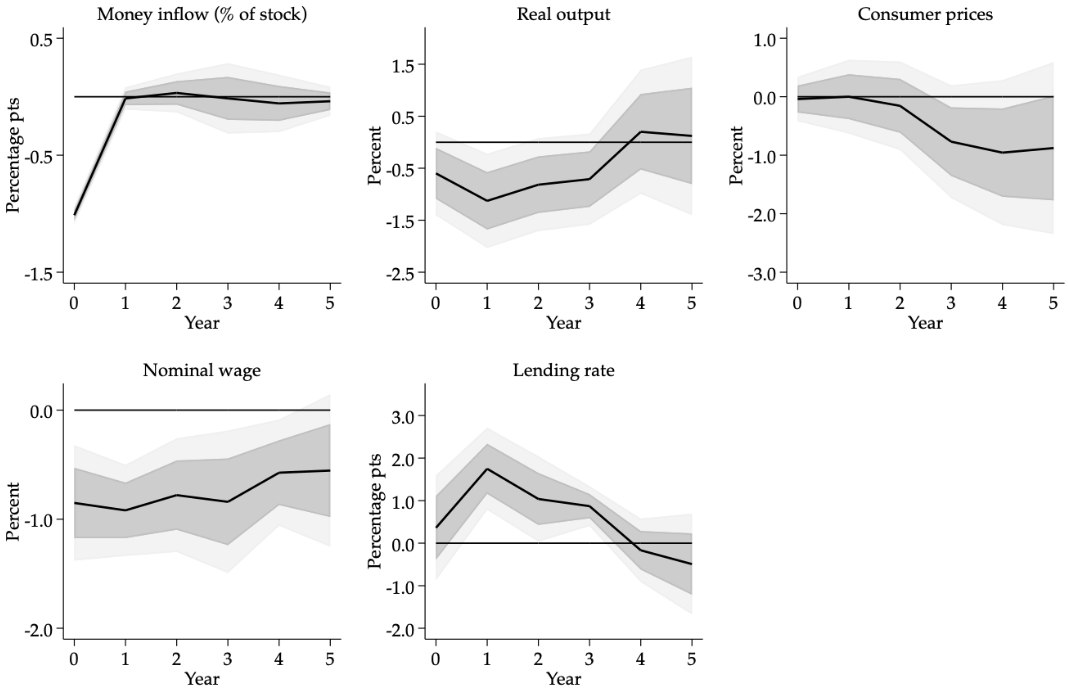
Notes: Results based on an alternative shock series that assumes that the news of maritime disasters arrived in Spain one month later than assumed in the baseline series.

Figure B.10: Placebo test



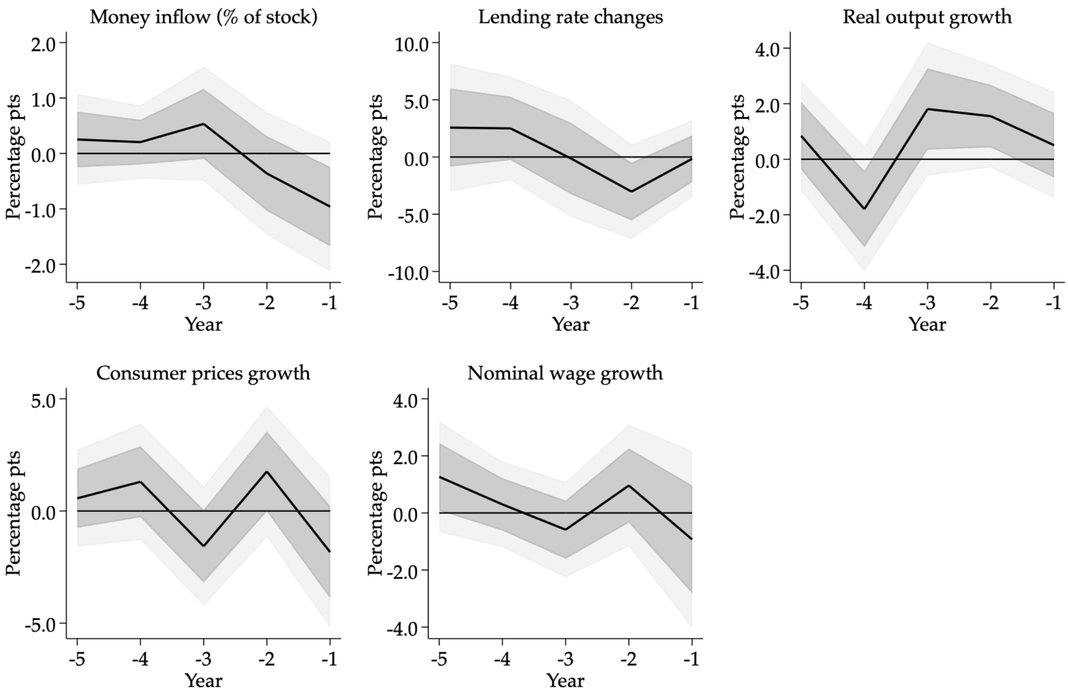
Notes: Black line – baseline IRF. Grey area – 10% to 90% percentile range based on 500 IRFs for temporally randomly reshuffled money shocks.

Figure B.11: Impulse responses for negative 1 ppt money inflow shock (pre-1780 sample)



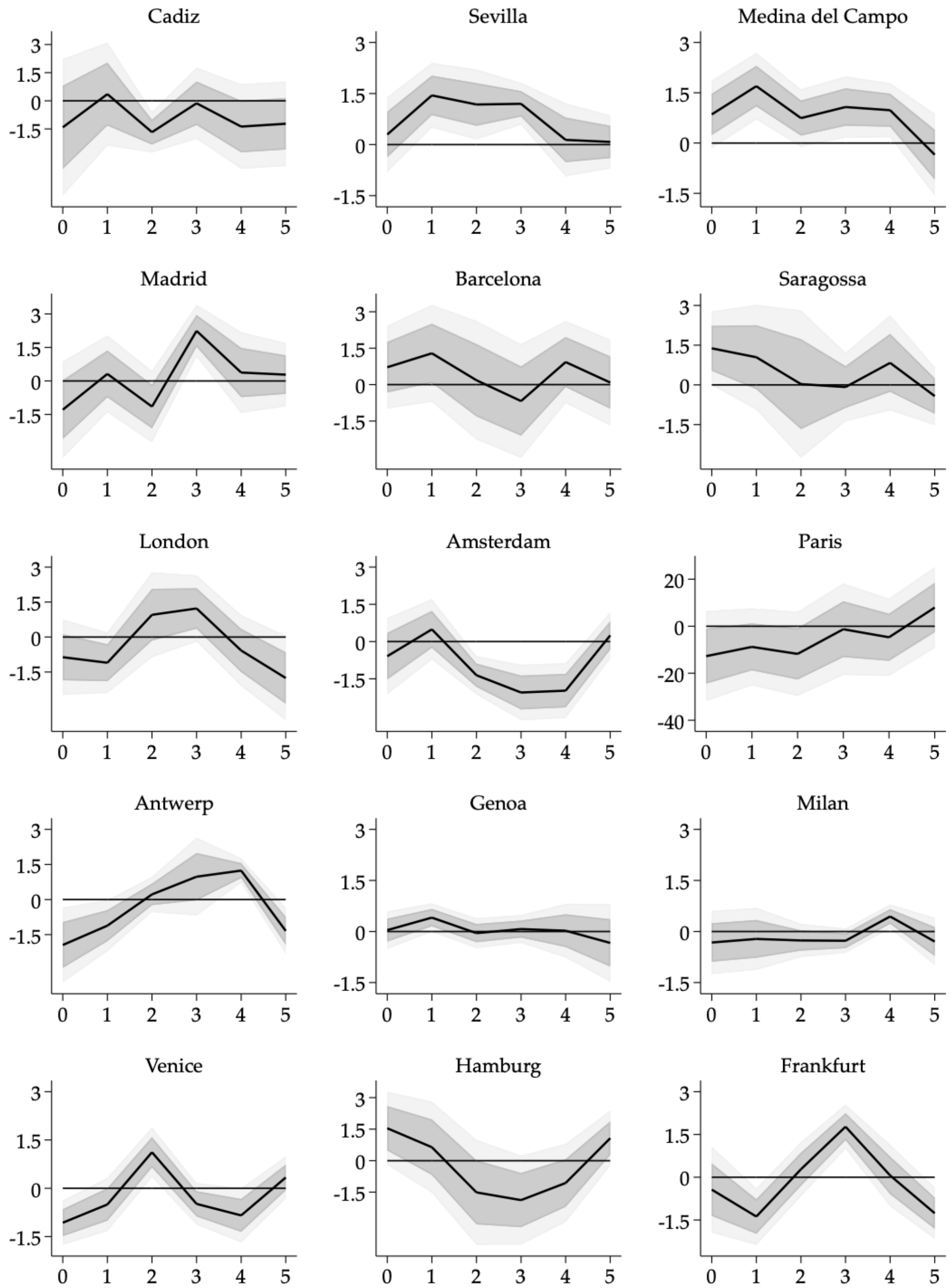
Notes: This figure shows IRF results based on a pre-1780 sample to remove any influence of structural changes occurring at the end of the 18th century.

Figure B.12: Pre-event analysis



Notes: Black line – average growth rate of variables prior to maritime disaster years compared to non-disaster years.

Figure B.13: European interest rate responses (negative 1 ppt money inflow shock)



Notes: y-axis – percentage points. x-axis – years. The figure shows the IRFs for those cities where the available data allows for the construction of long-run lending rate series. The lending rate series for each of these cities straddles at least 15 maritime disaster events. Only the series for Cadiz straddles fewer disaster events, because its observations are concentrated in the 18th century. Its IRF is nevertheless shown here, because the Cadiz series goes into the average Spanish lending rate series. Lending rates in some non-Spanish cities actually decreased (e.g. Amsterdam), possibly indicating a "run to safety" response, in which lending retracted from Spain and moved to safer destinations in the aftermath of maritime disasters.

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